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OPTIMAL LOADOUT OF THE SUPPLY CLASS (AOE 6) FAST COMBAT STORES SHIP

by

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September, 1995

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OPTIMAL LOADOUT OF THE SUPPLY CLASS (AOE 6) FAST COMBAT STORES SHIP

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ABSTRACT

This analysis develops a methodology to determine the optimal loadout for the Supply (AOE-6) class fast combat stores ship. The methodology employed tests the ability of a Supply class AOE station ship to resupply and rearm a battle group for offensive operations, including combat. Given a generic scenario, the AOE-6 is loaded with ordnance that provides the maximum benefit to the battle group. Once the AOE-6 is loaded with ordnance, several generic battle groups are developed where the quantity of each necessary commodity in the battle group is tracked daily, and the consolidation schedule for the AOE-6 is determined. From this data, the optimization model finds the minimum number of CONSOLs required to maintain the minimum levels and consequently the optimal cargo fuel mix to configure the AOE-6 station ship. The output for each battle group composition is then analyzed and a cargo fuel mix for the AOE-6 is determined that will respond to the largest number of possible tasking with minimum reconfiguration of fuel tanks.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ACRONYMS

AAW	Anti-Air Warfare
ACE	Air Combat Element
AE	Ammunition Ship
AFS	Combat Stores Ship
ALSS	Advanced Logistics Support Site
AMRAAM	Advanced Medium Range Air-to-Air Missile
AO	Fleet Oiler
AOE	Fast Combat Stores Ship
AOR	Fleet Replenishment Oiler
ARG	Amphibious Readiness Group
ASROC	Anti-Submarine Rocket
ASUW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
AUR	All Up Round
CG	Cruiser
CH	Cargo Helicopter
CINCLANTFLT	Commander-in-Chief, U.S. Atlantic Fleet
CIWS	Close-In Weapons System
CLF	Combat Logistics Force
CONSOL	Consolidation
CONREP	Alongside Replenishment
CPS	Chemical Protective System
CV	Aircraft Carrier
CVN	Nuclear Powered Aircraft Carrier
CVS	Anti-Submarine Aircraft Carrier
CVW	Carrier Air Wing
CV/CVNBG	Carrier Battle Group
DD	Destroyer
DDG	Guided Missile Destroyer
DFM	Distillate Fuel Marine`
GAMS	General Algebraic Modeling System
HARM	High Speed Anti-Radiation Missile

JP-5	Aviation Fuel
LAMPS	Light Airborne Multi-Purpose System
LDO	Limited Duty Officer
LHA	Amphibious Assault Ship
LOGGRU	Logistics Group
LPD	Amphibious Transport Dock
LSD	Amphibious Landing Ship
MEU	Marine Expeditionary Unit
MHE	Material Handling Equipment
MK	Mark
MOE	Measure of Effectiveness
MSC	Military Sealift Command
NALC	Naval Ammunition Logistics Code
NASSCO	North American Ship and Steel Company
NATO	North Atlantic Treaty Organization
NPS	Naval Postgraduate School
NSFS	Naval Surface Fire Support
SLAM	Stand-Off Land Attack Missile
SLEP	Service Life Extension Program
STREAM	Standard Replenishment Alongside Method
SURFLANT	Surface Forces Atlantic
SURFPAC	Surface Forces Pacific
TACLOGS	Tactical Logistics System
UNREP	Underway Replenishment
VERTREP	Vertical Replenishment
VLS	Vertical Launch System

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EXECUTIVE SUMMARY

With the commissioning of the USS Supply (AOE 6), a new class of fast combat stores ship entered fleet. The lead ship in a class of four, Supply brings to the fleet the latest features in combat survivability, habitability and underway replenishment technology. In 1952, Admiral Arleigh Burke spoke of the need of a multi-product underway replenishment ship with the ability to transfer several commodities simultaneously as well as the speed to travel with a carrier battle group. The Supply Class is the fulfillment of Admiral Burke's desire.

The purpose of this research is to develop a methodology to determine the optimal loadout for the Supply (AOE-6) class fast combat stores ship. Current operational planning indicates that a fast combat stores ship will deploy with each carrier battle group to act as an on station resupply ship. The methodology employed in this research tests the ability of a Supply class fast combat stores station ship to resupply and rearm a battle group for offensive operations, including combat.

To complete this research, a generic scenario was developed that required the Supply (AOE 6) to enter a weapons station to complete an ordnance onload. Linear programming techniques are employed to ensure the AOE-6 is loaded with ordnance that provides the maximum benefit to the battle group. Once the AOE-6 is loaded with ordnance, several generic battle groups are developed where the quantity of each necessary commodity in the battle group is tracked daily, and the consolidation schedule for the AOE-6 is determined. From this data, the optimization model finds the minimum number of CONSOLs required to maintain the minimum levels and consequently the optimal cargo fuel mix to configure the AOE-6 station ship. The output for each battle group composition is then analyzed and a cargo fuel mix for the AOE-6 is determined that will respond to the largest number of possible tasking with minimum

reconfiguration of fuel tanks.

The final product of this research is the development of two optimization models. The first model, when loaded with the correct data for a particular ship platform, will load ordnance in a safe, compatible manner, using ordnance utilities provided by the programmer. The second model will aid a logistics planner in determining a replenishment schedule for a deployed battle group. Be optimizing the replenishment schedule, the logistics planner can also determine the optimal cargo fuel mix to be carried aboard the Supply class fast combat stores ship.

I. INTRODUCTION

A. BACKGROUND

The demise of the former Soviet Union forced a major restructuring of the United States Defense establishment. With a shrinking fleet and a shrinking budget, strategic overseas logistics bases were no longer fiscally, or politically, possible to maintain. In this post Cold War era, the Navy has operated under the "... From the Sea" strategy [Ref. 1]. This vision of Navy/Marine Corps operations in the post Cold War era was recently updated. The new strategy paper is titled "Forward ...From the Sea" and this new vision provides the outlook for the Navy/Marine Corps team in the overall national strategy [Ref. 30]. The significant aspect of this updated strategy is that despite budget cuts, a shrinking fleet and the reduction of overseas support bases, the Navy will still be asked to fulfill the same commitments. This means that the Navy of tomorrow must be flexible, capable and ready to accomplish an ever increasing variety of missions.

The key ingredient to any successful military campaign, from a full blown shooting war such as Desert Storm, to a humanitarian mission such as Restore Hope in Somalia or Restore Democracy in Haiti, is logistics. For the Navy, this means making sure the forces in the fleet have the fuel, food, ordnance and spare parts to keep the people, ships and aircraft operational for extended periods of time. One important part of the logistics pyramid is the logistics ships that transfer the necessary commodities for sustainment from supply sites ashore to the combatants at sea. The development and refinement of the Combat Logistics Force (CLF) has and will continue to be the force multiplier that enables the United States fleet to maintain the flexibility required in this post cold war era [Ref. 8: p. 1].

The US Navy is the world's superior navy not only because of its weapons, but because of its people and its extraordinary ability to logistically support its battle groups for sustained operations at sea [Ref. 5: p. A-3]. The ability to resupply without entering port is the key to a battle group's ability to remain on station indefinitely. With technology developed throughout this century, and greatly enhanced since the 1950's, the United States has nearly perfected the task of underway replenishment (UNREP) [Ref. 2: pp. 4-7], able to transfer almost any commodity, day or night in almost all weather conditions. The notable exception is the ability to transfer vertically launched weapons without having to enter port, which is the major challenge currently facing the UNREP community. With the deployment of vertically launched weapons aboard most surface combatants, a safe method of transfering and reloading vertically launched weapons at sea needs to be developed, tested, evaluated and implemented into the fleet.

1. Development and History of the CLF

UNREP became operational with a limited fueling at sea capability in 1917. The operational transfer of ammunition and stores occurred near the end of World War II. The first UNREPs were conducted by single product replenishment ships that would resupply the battle group with one particular commodity. The underway replenishment fleet consisted of ammunition ships (AEs), fleet oilers (AOs) and combat stores ships (AFSs). A historical time line detailing the development of UNREP and the CLF force is shown in Appendix A.

With the defense structure designed to counter the Soviet threat in the 1960's, the concept of the multi-product, all weather capable UNREP ship was put to sea with the Sacramento (AOE 1) class fast combat stores ship in 1963. This class of ship was specifically designed to deploy with a carrier battle group (CVBG). While the maximum speed of any single product replenishment ship was 20 knots, the AOE-1 class has a maximum speed of over 30 knots, fast enough to conduct a high speed transit with an aircraft carrier. The AOE-1 class greatly reduced the amount of time a combatant conducted UNREP evolutions with a CLF ship by providing the receiving ship "one stop shopping" for parts, food, ordnance and fuel. This dramatically decreased the time ships were vulnerable to attack. The AOE-1 class proved to be such a good concept that it has become a permanent member of the battle group, able to replenish any ship, any time, with any commodity [Ref. 2: p.14].

In the mid 1960's, the fleet replenishment oiler (AOR) was developed for the purpose of deploying with smaller anti-submarine warfare (ASW) aircraft carriers (CVS). Older WW II Essex class aircraft carriers were reassigned to the role of carrying ASW aircraft to track and prosecute submarines. Due to the great reduction in the wartime ordnance usage rates with this new tasking, the AOR contains only a small fraction of the ordnance storage capacity, travels at a maximum speed of 20 knots and has half the ammunition transfer rate of an AOE. The AOR served as a station ship for carrier battle groups during the Vietnam war when its slow speed and minimal ordnance capacity could be compensated for by the close distance between the theater of operations and the resupply base in Subic Bay, RP. It was during the remote Indian Ocean operations of 1979 that the problems associated with assigning an AOR as the lone resupply ship to a battle group surfaced. Their lack of ordnance storage capacity required that an AE travel with the CVBG. This meant that the CVBG commander had to plan for two ships that were unable to exceed 20 knots. While the AOR continued to deploy for many years with carrier battle groups this class of ships is currently being decommissioned [Ref. 2: p. 36].

2. Role of the AOE in Current CLF Planning

Today's operational and logistics planners have developed a comprehensive and responsive logistical support system. This system includes air and sealift, replenishment ships, mobile repair facilities and advance logistics support sites (ALSS). The area of emphasis for the CLF ship will be the movement of commodities from the ALSS to the battle group. The movement of commodities from the ALSS to the battle group will be carried out by the single product ships previously described. These ships are called shuttle ships. Current plans are for these ships to be manned by civilian crews with military detachments aboard and managed by the Military Sealift Command (MSC)[Ref. 5: p. A-1]. These single product ships deliver their commodities to a multi-product ship called a station ship [Ref. 8: p. 2]. The station ship then distributes the commodities to the battle group as required. The station ship will have a military crew. The role of the AOE is to act as a station ship for a CVBG.

3. Role of the AOE-6 Class in Future Operations

The shape and composition of today's CLF force is rapidly changing. The decommissioning of AORs, older AEs and AOs, transfer to MSC of AFSs and newer AEs all highlight this change. An entire class of AOs (Kaiser Class) has been built from the keel up with the intent of being operated by MSC. One thing that does remain constant, the station ship of the future will continue to be the AOE. However, the small number, four, and advance age of the AOE-1 class (the last AOE-1 class ship, Detroit (AOE 4), was commissioned a quarter of a century ago) shows a need for a new generation of CLF station ships to enter the fleet [Ref. 8: p. 4]. Technological improvements in the areas of propulsion, ship's defense and commodity storage have led to the development of a follow on class to the AOE-1. This new class is named the Supply class (AOE 6). The lead ship in the class was commissioned in February, 1994 and is currently undergoing workups for its maiden deployment.

Other students have completed studies detailing optimal loadouts for different CLF ship classes [Refs. 8 and 9]. The AOE-6, however, is new with several advanced design features. Current plans call for four Supply class AOEs to join the fleet. At the present time, no money has been allocated for a follow-on class to the AOE-6. The bottom line is that for the Operational Logistician, this class of ship will be a mainstay of fleet resupply for many years to come and provides excellent research opportunities that can directly impact fleet operations in the near future.

B. THESIS OBJECTIVES

The goal of this thesis is to demonstrate the capability to optimally load the AOE-6 class for CVBG operations. The measure of effectiveness(MOE) for this goal will be to maximize the length of time a given CVBG can remain on station without requiring outside logistical support. This objective will be accomplished in two phases.

The first phase is to develop a method to generate optimal ordnance load lists for CLF ships operating with CVBGs. The surrogate MOE for this step will be to maximize the usefulness of the ordnance based upon the storage constraints and the utilities of each ordnance type. This will be accomplished be developing a computer model that will output the number and storage location for each ordnance type.

The second phase is to develop a method to track commodity reserve levels and usage levels for a CVBG. This will involve the development of a second computer program to track the status of commodities in a CVBG. The goal of this program is to analyze how often the battle group needs to be replenished during different phases of operations. This analysis will also find the optimum mix of cargo fuel for the station ship to carry.

In the end, two separate computer programs will be generated, each addressing one of the two phases discussed above. The developed models will first present an optimal ordnance loadout list for an AOE-6 for a given mission, and then detail how often and how much of a given commodity must be transferred from the shuttle ships to the station ship to keep the carrier battle group supplied at an acceptable level. The model designed to track commodity usage will also show the optimal distillate fuel marine (DFM) to aviation fuel (JP-5) mix for the AOE-6.

1. Thesis Organization

This thesis is organized in such a manner as to highlight for the reader the methodology that will be employed to attain the goals stated in the previous paragraphs. The first step will be to introduce the Supply Class AOE to the reader. Information concerning the development, the storage and UNREP capabilities as well as the new design features of this class will be highlighted. The second step will be to develop a realistic, threat based scenario in which to test the capabilities of the AOE-6. This step will detail the forces that will require resupply as well as the expected commodity usage rates for a potential CVBG. The next step is to look at developing a method of ordnance prioritization based upon our developed scenario that will allow the generation of an optimal ordnance load list. The fourth step is to detail the mathematical formulation of the two computer programs. The final step will be to look at the results of the two computer programs and provide conclusions based upon the results.

2. Scope of Study

In addition to attaining the goals stated previously, sensitivity analysis will be conducted to show how the optimal cargo fuel mix carried aboard the AOE-6 will change if a fossil fuel powered carrier (CV) is substituted for the nuclear powered carrier (CVN) and how the number of CONSOLs is impacted. Further sensitivity analysis will be conducted by adding a three ship Amphibious Ready Group (ARG) to see how this effects the number of CONSOLs required in the first two (CVN and CV) model runs. The impact of lowering the minimum commodity levels will have on the number of and length of time between CONSOLs will also be investigated as will reducing the number of escorts assigned to the CVBG. The impact of reducing the number of escorts assigned to the battle group will also be analyzed to see if a significant change occurs in the recommended mix of cargo fuel carried by the AOE-6. In all studies of sensitivity analysis, the possibilty of end effects, the fact that the operation ceases at a fixed time, will also be investigated to see if the end effects impact the final results.

The final probe of this thesis will look at the storage capacities of the AOE-1 class as compared to the AOE-6 class. Just looking at raw numbers, the AOE-1 class carries more fuel, ammunition, stores and has more UNREP stations then the AOE-6 class. What impact would using an AOE-1 as the station ship have on the number of CONSOLs required and the length of time the battle group can be without resupply? Are the qualitative improvements in the design of the AOE-6 class worth the loss of commodity capacity and UNREP capability you have with the AOE-1 class? The goal is to rerun both models and analyze the difference in the amount of ordnance that can be stored on the AOE-1 as compared to the AOE-6 and how the required number of CONSOLs differs between the two ship classes.

II. SUPPLY CLASS FAST COMBAT STORES SHIP

A. INTRODUCTION

The AOE-6 design was intended to be a significantly improved design compared to the AOE-1 class. The main areas of improvement were to be combat survivability and habitability . This is the first ship class to go through the Ships Characteristics Improvement Board process and several changes were made to the original design based on the Board's input [Ref. 14: p. 2]. This process looks at improving the overall quality of life aboard ship. A few of the many improvements as a result of this process include improved sanitary facilities, training classrooms, physical fitness facilities, self service laundry and specific berthing for transient personnel [Ref. 14: pp. 27-31]. The contract design started in July, 1983 with the first ship commissioned in 1994.

The original plan called for funding five ships in the Supply class. North American Steel and Shipbuilding Company (NASSCO) in San Diego, CA. was awarded the contract to construct the first three (AOE 6-8) ships in the class. After the funding was dropped for the fifth ship, causing a lengthy delay in contract negotiations, plans to build AOE-9 were cancelled. When the decision was made to proceed with the construction of the fourth and final ship in the class, AOE-10, NASSCO was again awarded the contract [Ref. 18]. The lead ship in the class, USS Supply (AOE 6), is homeported in Norfolk, VA assigned to the Atlantic fleet. The second ship in the class, USS Rainier (AOE 7), is homeported in Everitt, WA, assigned to the Pacific fleet.

While the primary focus of this research effort is on commodity storage, some important design features should be highlighted. The ship class is 753 feet long, 107 feet wide (to fit through the Panama Canal), with a full load displacement of 48,500 tons. The crew is made up of over 660 officers and men including the embarked air and explosive ordnance disposal detachments. To reduce the manning required in the engineering department (from 162 to 113), as well as meet maximum noise level requirements (84 db), the engineering plant design was altered from a steam plant to four LM-2500 gas turbine engines [Ref. 14: p 73]. These engines power two shafts, providing a maximum speed of 30 knots. This compares to the AOE-1 class, which is powered by four 600 psi steam boilers and is capable of 32 knots.

AOE-6 class armament includes the NATO sea sparrow missile launcher, two Close in Weapon Systems, two 25mm chain guns and four 50 caliber machine guns for ship defense [Ref. 14: p. 152]. Passive ship defense features, such as a Chemical Protective System (CPS) for defense against chemical attacks and special hardening of electronic systems to prevent shock damage in the event of a nuclear attack, were also included in the construction. The CPS provides full protection in a chemical, biological and radiological environment to 54% of the ship's interior areas. These areas include the bridge, combat information center, living spaces and all operating spaces [Ref. 14: p. 4]. For added protection, both in combat and to protect the environment, this ship class has double hull construction. While the AOE-1 contains the same active defensive armaments, their design does not contain the passive features. Due to the large crew size, fully equipped medical and dental facilities are also located aboard.

While this ship was designed during the cold war, it was built during the draw down that followed the fall of the Soviet Union. In an effort to save money, an entire ammunition hold, or 56 ft of ship length, was deleted from the original design. The AOE-6 class currently has three holds with a total of 277,000 cubic feet of designed ordnance storage area. This cost cutting effort saved the Navy an estimated 56 million dollars [Ref. 18], or roughly 1 million dollars per foot, but forced the ship to reduce its maximum design storage capacity by 20% for food and stores, 25% for fuel and 25% for ammunition [Ref. 14: p. 4]. While suggestions have been made to "jumboize" the AOE-6 class, similar to what the Navy did with the AO-177 class oiler, to regain the lost 56 feet, no money has been allocated or plans developed to date to perform the work [Ref. 4: Appendix B].

B. UNREP CAPABILITIES

The mission of the fast combat support ship is to provide the CVBG with one stop shopping for ammunition, fuel and stores. To do this mission the AOE-6 uses a combination of helicopters for vertical replenishment (VERTREP) and UNREP rigs for alongside, or connected replenishment (CONREP). A 35 foot workboat is included in the ship's complement to provide services for inport replenishment [Ref. 14: p. 62].

The Supply class is constructed with three helicopter hangers and a flight deck on the aft portion of the ship. Plans and funding have been approved to convert the port side hangar into a storage and pre-stage area for the gear necessary to conduct VERTREPs [Ref. 18]. Operational plans call for the AOE-6 to deploy with two CH-46 helicopters and necessary flight crews and maintenance personnel to perform required VERTREP missions. The flight deck is certified to land CH-53 helicopters [Ref. 14: p. 12]. Some of the biggest design improvements for this class over the AOE-1 class have been in the area of embarked air detachment work habitability. A real emphasis was placed on making the designated work areas more efficient. Specific examples include a sanitary facility near the hanger area, a separate, smaller battery charging area and a small arms locker which all contribute to improved working conditions and efficiency for the embarked air detachment [Ref. 14: p. 65].

The "main batteries" of the CLF ship are the fuel and cargo delivery stations. The AOE-6 class is outfitted with six cargo delivery stations and five refueling stations. The port side of the AOE-6, the side that handles the aircraft carrier, has three cargo STREAM rigs and three double hose fueling stations. This is one less cargo station than the port side of the AOE-1 class ships. The aft, port station (Station 14) on the AOE-6 was deleted to cut costs [Ref. 14: p.27]. Funding has been authorized to install the station at the first available opportunity [Ref. 18]. Appendix B provides a topside view of the UNREP stations and flight deck areas.

The AOE-6 manning allows for ten UNREP rig crews and full VERTREP flight operations as outlined in the Required Operational Capabilities (ROC) and the ships manning documents [Ref. 14: p.23]. This allows for six crews to be working the six rigs to the aircraft carrier, three crews working a smaller ship to starboard and one crew in standby.

To aid in the movement of ammunition and stores, the ship is assigned over 30 pieces of material handling equipment (MHE). Major pieces of MHE include four 8,000 pound electric, six 6,000 pound electric, and ten 6,000 pound diesel forklift trucks, which are all standard navy design. Four 10,000 pound electric side loading forktrucks modified for reduced height are included for handling missiles and engines. The side loaders used on the Supply are unique to the AOE-6 class which may cause a maintenance problem because of a lack of spare parts [Refs. 18&19]. One special 10,000 pound electric pallet truck is also provided for handling cable reels. Staging areas are located on the O-1 level to handle material and pre-stage for UNREPs.

Two design flaws that impact how UNREP operations take place must be mentioned. The first is a flaw in both the AOE-1 and the AOE-6 classes. The cargo doors and the elevators do not match up on either class. This means that when a fork lift operator brings his load through the cargo doors he must perform an S-turn to align with the elevators. For smaller loads with a clear deck this does not pose a problem, but when large number of missiles start being transferred, this can prove to be a time consuming nemesis. In an effort to compensate for this flaw, multi-directional forklift trucks are available on the AOE 6 class. The second flaw, unique to the AOE-6 class, is that the alleyways leading from the cargo handling areas back to the flight deck are limited by the bulkhead, overhead and other structures to an eight foot by eight foot box. This means that any commodity longer then eight feet must be carried by the modified, reduced height side loader (with a two inch clearance) or else transferred by CONREP vice VERTREP. Again, not an impossible problem, but one that definitely needs to be included in the planning factors when transferring missiles [Refs. 14 and 19]. The AOE-6 class has one cargo stream receiving station located aft on the starboard side [Ref. 5: p. B-2].

C. AMMUNITION STORAGE

The Supply class is designed with four holds, number one being forward number, four furthest aft. Appendix C provides a top and side view of the cargo hold configuration for the AOE-6 class. Ammunition is stored in the forward three holds. Each hold is serviced by two elevators to provide fail safe handling capability. Hold one is serviced by two 12,000 lb. elevators and has three separate levels. Hold two and three are each serviced by two 16,000 lb. elevators and each hold has four separate levels. All six weapon elevators are located centerline on the ship to maximize hold utilization and all terminate at the transfer deck to minimize cargo handling [Ref. 14: p. 40]. The elevators in holds 2 and 3 are long enough to handle vertically launched (VLS) Tomahawk missile containers.

The design of the second and third holds is such that the two elevators bisect each of the four levels. The elevator shaft is enclosed fore and aft by ship's watertight bulkheads. The port and starboard sides are enclosed by standard navy J doors. Current federal regulations state that for an area to be a separated weapons storage area, a permanent steel bulkhead must be in place [Ref 3: p. 1,077]. This regulation means that currently a total of 11 separate storage decks are available on the AOE-6 for ammunition. Efforts are now underway to append this regulation to state that a closed J door, the type of doors located on each side of the ordnance elevators, will be authorized to act as a permanent steel bulkhead [Ref. 15]. If the J doors can be treated the same as a permanent bulkhead, this will give the Supply class 19 separate storage areas, by dividing holds 2 and 3 in half. This modification is vital when the issue of weapons storage compatibility is factored into the load planning. Certain weapons such as the Harpoon missile can not be stored with other weapons. In the case of the Harpoon, the combination of an explosive warhead and the flammable liquid fuel make it explosive compatibility group J [Ref. 16: p. 2-18]. This means that only other J type weapons, of which there are currently none in the inventory, S type weapons (Chaff or Sonobouys) or inert items such as practice bombs, wings and fins can be stored with this weapon [Ref. 16: p. 2-18 and Ref. 3: p.1,011]. So if an AOE's tailored load list calls for five Harpoon missiles, or other ordnance that requires special handling, the potential exists for many cubic feet of valuable storage area to be wasted.

The total designed ammunition load is 1,800 tons [Ref. 14: p. 6]. The deck stress is 675 lbs. per square foot for the 2nd deck of all three ordnance holds. The hold level as well as the 1st and 2nd Platform levels all are rated at 1,000 lbs. per square foot [Ref. 15].

In anticipation of the requirement to carry larger quantities of VLS Tomahawk missiles, space has been reserved in the overhead of the 2nd Deck and 1st Platform levels of holds 2 and 3 to install monorail air hoists. This monorail will transport the missiles from the handling deck directly to magazines, greatly reducing the ordnance handling time. This monorail system will permit 20% greater stowage density and handling flexibility of VLS Tomahawks and other long missiles [Ref. 14: p. 43]. Naval Sea Systems Command is currently reviewing different maintenance and funding options to complete this work [Ref. 18].

1. Ordnance Stowage Planning Factors

To aid in planning, two important stowage factors are used by load planners. First, a stowage factor of .8 is used by Naval Weapons Station, Earle [Ref. 15] to insure that only 80% of the available space is used by the AOE prior to deployment. This means that 80 percent of the volume in the storage areas will be designated to contain ordnance, so that a 10,000 cubic feet area will have 8,000 cubic feet of ordnance. This planning factor allows for retrograde of ordnance from Europe, Japan or Guam as well as missile swapping and other necessary operations. The second stowage factor is .7. This allows extra room for storage, dunnage, maintenance and working space in the ordnance storage areas. It is also very important that enough room be left for MHE to operate in the holds. These two factors are used in determining a final "usable" cubic feet of storage area available for weapons stowage. Table 1 shows the useable cubic feet available for each deck, taking into account both stow factors (.8 X .7). It must be remembered that 20% of the ordnance storage capacity of the AOE-6 will be utilized after the ship has deployed.

Table 1 AOE 6 Ammunition Storage Characteristics

Storage Area	Usable Cubic Feet	Square Feet of Deck Space
1st Ammo Hold, 2nd Deck	12,300	2,070
1st Ammo Hold, 1st Platform	12,300	2,070
1st Ammo Hold, 2nd Platform	12,200	2,010
2nd Ammo Hold, 2nd Deck	13,600	2,240
2nd Ammo Hold, 1st Platform	13,600	2,240
2nd Ammo Hold, 2nd Platform	11,900	2,240
2nd Ammo Hold, Bottom Hold	11,800	2,200
3rd Ammo Hold, 2nd Deck	12,550	2,220
3rd Ammo Hold, 1st Platform	13,600	2,240
3rd Ammo Hold, 2nd Platform	11,600	2,240
3rd Ammo Hold, Bottom Hold	11,500	2,200
11 total storage areas	**136,950**	

2. Method of Ordnance Storage

This class of ship relies on the diagonal metal dunnage system to provide a secure method of ammunition storage. Dunnage includes the metal stanchions that hold the ordnance in place as well as the material, usually wood, that is placed between the pallets or containers of ordnance to prevent shifting and damage that may be encountered with heavy seas. The deck space is divided into blocks to accommodate almost all ordnance dimensions. Portable aluminum stanchions are inserted vertically into the deck and overhead. The aluminum stanchions are designed so that the corners of the ordnance storage containers fit into the corner of the stanchion allowing for secure storage with a minimum of wood dunnage. This design is very efficient and allows for maximum use of valuable ordnance storage space. This stanchion design also makes it faster to stow and unstow ordnance by not requiring horizontal stanchions and chains to be used. It should be noted that these stanchions are new and have not yet been tested in the fleet [Ref. 14: pp. 42-44 and Ref. 15].

D. STORES AND PROVISIONS

The fourth hold, the one farthest aft, is for the storage of dry, refrigerated and frozen goods. This hold has four levels with the top level, the second deck, being used for dry stores. The lower three levels are for chilled and frozen goods. The fourth hold is serviced by one 12,000 pound elevator and a pallet conveyor, both centerlined to maximize utilization. The pallet conveyor is rated to carry 3,000 pound, palletized loads [Ref. 14: p. 49]. The total storage area is 90,400 cubic feet, of which 54,000 is refrigerated [Ref. 5: p. B-1], with an expected stow factor of .8. This compares to the AOE-1 class which has 105,000 cubic feet of stores with 60,000 being refrigerated [Ref. 5: p. B-2].

E. CARGO FUEL SYSTEM

The cargo fuel system for the AOE-6 class has the capacity to carry over 7 million gallons of DFM and JP-5. For environmental safety, a stow factor of .95 is used. There are a total of 24 tanks. Eleven tanks are coded for JP-5, with a total of 2,812,225 gallons or 40% of the total DFM/JP-5 capacity. Eight tanks are coded for DFM and these hold a total of 1,963,213 gallons or 30% of the total capacity. A design feature of the AOE-6 class is that five tanks are convertible, that is they can carry either JP-5 or DFM. This gives the battle group commander the capability and flexibility to configure each of these five tanks to contain either JP-5 or DFM, providing the battle group maximum sustainment. The total capacity of these five convertible tanks is 2,281,462 gallons which is 30% of the total fuel capacity. The AOE-6 class can carry a cargo fuel load that can have either a maximum of 70% JP-5 or 60% DFM. Table 2 shows the capacities of each tank while Appendix D provides a schematic view of the system.

Table 2 Cargo Fuel Tank Capacities

Compartment Number	**100% Capacity in Gallons**	**100 % Capacity in Barrels**
7-44-0-JJ	108,365	2,408
7-105-0-JJ	386,333	8,585
7-205-0-JJ	18,533	412
7-205-1-JJ	305,753	6,795
7-205-2-JJ	340,764	7,513
7-297-2-JJ	283,340	6,296
7-297-1-JJ	283,335	6,296
7-265-2-JJ	228,921	5,087
7-265-1-JJ	228,917	5,087
7-362-1-JJ	313,981	6,977
7-362-2-JJ	313,983	6,977
7-65-0-FF	336,200	7,471
7-245-0-FF	213,334	4,740
7-395-2-FF	282043	6,268
7-395-1-FF	282,040	6,268
7-425-2-FF	226,404	5,031
7-425-1-FF	226,400	5,031
7-430-0-FF	24,758	550
7-565-0-FF	372,034	8,267
7-150-0-FF/JJ	791,754	17,595
7-265-0-FF/JJ	445,200	9,893
7-330-0-FF/JJ	445,195	9,893
7-330-2-FF/JJ	299,658	6,659
7-330-1-FF/JJ	299,655	6,659
Total of 24 Tanks	**7,056,900**	

Note: JJ are coded to carry JP-5, FF carry only DFM and JJ/FF are convertible.

For these convertible tanks to be a useful asset, commanders must understand the process to convert a tank from one fuel system to the other. Each of the convertible tanks has the necessary 10 to 12 feet of piping to connect it with either the DFM or JP-5 fuel pumping system. This piping is copper-nickel for the DFM system and steel for the JP-5 system. If the tank is designated to carry JP-5, the tank must be opened, gas freed and ship's force personnel must enter the tank. A blank flange is placed on the DFM suction piping and the blank flange from the JP-5 suction piping is removed. The most time consuming portion of this process if the tank is empty is to certify the tank to be gas freed [Ref. 18]. After the piping has been properly aligned, the cargo fuel control console will be updated to show that this tank is now a JP-5 tank. If the tank is being converted from DFM to JP-5, additional time will be spent flushing and "mucking" out the tank prior to introducing JP-5. This step is necessary to maintain the quality standard of the JP-5. This step is not necessary when converting from JP-5 to DFM [Ref. 18].

The decision of which fuel to place in each tank is based on the propulsion of the aircraft carrier and number of escorts assigned. If the carrier is nuclear powered, more JP-5 can be carried vice DFM. The actual decision is made by the immediate superior type commander, usually the Logistics Group (LOGGRU ONE on the west coast, LOGGRU TWO on the east coast) for that operating area. This decision will be made after consulting with the Battle Group commander and the Surface Type Commander (SURFPAC or SURFLANT).

The AOE-6 class has a total of nine cargo fuel oil pumps, five for DFM and four for JP-5. Each pump has a 3,000 gallons per minute capacity. While the AOE-6 can fuel other ships from both sides, they can only receive CONSOL cargo fuel from three double hose receiving stations on the starboard side of the ship [Ref. 5: p. B-1].

While the AOE-6 class is designed to carry 21,000 barrels of fuel less then the AOE-1 class, a very important design feature was incorporated into the AOE-6. The AOE-1 is designed so that the cargo JP-5 is stored in the forward part of the ship. The cargo DFM is stored in the midships area. A constraint is placed on how large a difference can exist between the quantities of JP-5 to DFM because of stress to the hull caused by hogging and sagging. In an operational setting, sea water ballast can be used to fill this constraint. The AOE-6 does not have this constraint because the JP-5 tanks and DFM tanks are interspersed throughout the ship to prevent this problem as clearly shown in Appendix D. The constraint placed upon the AOE-6 is that the ship begins to lose stability as it approaches 30% of its liquid load. Again, sea water ballast can be used to compensate for this constraint. Both the AOE-1 and the AOE-6 classes have the ability to co-mingle bunker and cargo fuels.

III. SCENARIO DEVELOPMENT

The scenario developed for this thesis is designed to test the capabilities of the AOE-6 class station ship. This model was not developed to test a specific real-world threat, but is intended to demonstrate commodity usage for a CVBG during various phases of a possible future operation. The specific ship combinations are intended to reflect what would be considered a typical CVBG and ARG and provide useful information concerning commodity usage rates and resupply of forces afloat.

A. GENERAL CONCEPT

This scenario is based on historic use of the aircraft carrier and escorts in the roles of sea control, power projection ashore and demonstrating national interest by "showing the flag" abroad. The starting point for this scenario is a forward deployed nuclear powered aircraft carrier and six gas turbine powered escorts. The escorts include two Ticonderoga class cruisers, two Burke class destroyers, one Spruance class destroyer and one Kidd class guided missile destroyer. The CVBG is inport at an overseas United States Naval Facility that is co-located with a weapons station. One AOE-6 class fast combat stores ship is assigned to the battle group to serve as the station ship. A situation has developed in a region of the world that requires the carrier battle group to sail immediately to that area to show an American presence and await follow on tasking.

1. Description of Scenario

The United States is about to become involved in a possible regional conflict. The carrier battle group is currently inport but has been ordered to sortie and proceed to the region. It will take 10 days for the battle group to arrive. The ALSS has been reactivated and supplies are already being pushed into the theater.

In an effort to influence events without hostilities and to show United States resolve, the carrier battle group will proceed to a station 100 miles off the coast of the troublesome region and conduct a presence mission while at the same time gearing up for possible combat operations. This presence mission will last for 30 days.

When diplomacy fails the carrier battle group will be ordered to conduct combat operations. The mission of the CVBG will be to conduct strike operations (including naval gunfire support) against enemy bases preceding an amphibious invasion, with a secondary missions of neutralizing enemy submarines, establishing air and sea superiority and attacking possible enemy resupply routes.

Current intelligence indicates a medium ASW threat due to the recent delivery of several diesel submarines, a high ASUW threat comprised mainly of aggressive patrol craft and land based cruise missiles. A high AAW threat is largely due to the recent purchase and delivery of an undetermined number of fourth generation Ex-Soviet Union fighter and attack aircraft. The enemy has good air search radar and an adequate air defense missile system.

This scenario (Scenario 1) is intended to demonstrate how an AOE-6 with a nominal weapons loadout can proceed to a weapons facility and complete an onload of weapons determined to give maximum benefit to the battle group. This benefit is based upon a method of prioritization of each ordnance type that will be discussed in Chapter IV. This problem is realistic in the sense that AOEs currently deploy loaded at 80% usable capacity [Ref. 15]. The battle group will then proceed on an extended operation. The 80 day operation will be divided into three phases: transit, presence and combat. Each of the first phase, transit, will last 10 days, while the presence phase will last 30 days. The final phase, combat, will last 40 days. One of the purposes of modeling the CVBG during an extended operation is to find the optimal mix of JP-5 and DFM that will allow the battle group to proceed through the 80 day operation with a minimum number of CONSOLs between the station ship and shuttle ships.

The first modification to this scenario (Scenario 1A) will be to replace the nuclear powered aircraft carrier with a fossil fuel powered aircraft carrier. The second modification will be to have a three ship ARG join the CVBG in the operation. Scenario 1B will have a nuclear powered carrier while scenario 1C will have a fossil fuel powered carrier. The purpose of these modifications is to determine the impact on the number and frequency of CONSOL replenishments that will be required during the operation and determine if there is a change in the recommended mix of DFM and JP-5 to carry. Table 3 shows the ship combinations in each scenario modification:

Table 3 Battle Group Composition

Forces Involved	**Scenario 1**	**Scenario 1A**	**Scenario 1B**	**Scenario 1C**
CV Type	CVN-68 class	CV - 63 class	CVN-68 class	CV - 63 class
Escorts	2 CG-47 class 2 DDG-51 class 1 DD-963 class 1 DDG-993 class	2 CG-47 class 2 DDG-51 class 1 DD-963 class 1 DDG-993 class	2 CG-47 class 2 DDG-51 class 1 DD-963 class 1 DDG-993 class	2 CG-47 class 2 DDG-51 class 1 DD-963 class 1 DDG-993 class
Station Ship	1 AOE-6 class	1 AOE-6 class	1 AOE-6 class	1 AOE-6 class
Amphibious Forces	NONE	NONE	1 LHA 1 LPD-4 class 1 LSD-41 class Embarked MEU	1 LHA 1 LPD-4 class 1 LSD-41 class Embarked MEU

B. DATA BASE SPECIFICS

The purpose of this section is to clearly lay out for the reader the data that will later be used in the model formulation. This data will provide insight into the process that a logistics planner uses in determining the resupply requirements of a battle group. Based on this operational scenario and the data shown in this section, a model will be formulated to track and resupply four major commodities: DFM, JP-5, ordnance and stores. All of these commodities will be tracked as a whole in the battle group. Specifically in this section, the maximum quantity of each commodity possible at any time in the battle group as well as the battle group's daily commodity usage rate in each phase of the operation will be highlighted.

1. DFM

The maximum DFM available to the battle group involved in each scenario is found by summing the maximum fuel capacity for each ship in the scenario and adding the cargo fuel from the station ship and multiplying by the stow factor for fuel, .95. The stow factor for fuel is a safety factor for the environment to prevent fuel from being discharged into the ocean. In order to keep this document from being classified, the ship class fuel capacities used in this model are taken from the Unclassified TACLOGS Database [Ref. 27].

The battle group DFM daily usage rates are derived by summing the fuel consumed by the entire battle group for an average speed per day. During the scenario the following speeds will be used. The average transit speed will be 20 knots, 16 knots when operating with the ARG. The average presence, or patrolling, speed will be 12 knots and the average combat speed will be 16 knots for the carrier battle group and remain 12 knots for the ARG [Ref. 8: p. 22]. Daily ship fuel usage figures are derived from Naval Postgraduate Technical Report, Predicting Ship Fuel Consumption [Ref. 6]. Table 4 shows the daily fuel consumption for individual ship classes during the three phases of the operation as well as the maximum individual ship class fuel capacities. Table 5 shows the maximum DFM available to the battle group in each scenario as well as the battle group's daily usage rate for each phase of the scenario.

Table 4 Daily Ship (DFM) Fuel Consumption (Gallons per Day)

Ship Class	DFM Capacity (Gallons)	Daily Consumption 12 Knots	Daily Consumption 16 Knots	Daily Consumption 20 Knots
CVN-68	0	0	0	0
CV-63	2,000,000	61,810	81,408	121,944
CG-47	500,000	25,416	32,808	50,160
DDG-51	500,000	18,554	22,800	32,352
DDG-993	500,000	35,726	38,400	50,400
DD-963	500,000	35,726	38,400	50,400
AOE-6	700,000	29,513	39,929	61,200
LHA	1,500,000	33,566	50,400	
LPD-4	700,000	17,424	28,416	
LSD-41	700,000	8,664	14,313	

Note: AOE-6 DFM figure is ship's (bunker) fuel only.

Table 5 DFM Usage Rates (Gallons per Day) During Each Phase

Scenario	Maximum DFM Available	Transit Phase	Presence Phase	Combat Phase
Scenario 1	5,663,213-7,944,676	327,024	188,905	227,945
Scenario 1A	7,663,213-9,944,676	448,968	250,715	309,353
Scenario 1B	8,563,213-10,844,676	321,074	248,559	286,599
Scenario 1C	10,563,213-12,844,676	402,482	310,369	369,007

Note: DFM figure shows the range of DFM possible based on AOE-6 tank configuration.

2. JP-5

The operational tempo of the carrier air wing (CVW) and the Marine air combat element (ACE) will determine the daily battle group consumption of JP-5. The Naval Sea Systems Command report, Fast Combat Shuttle Ship AOE(V) [Ref. 25] provides the approximate figures for the combat phase of the scenario for the carrier air wing. The figures for the daily JP-5 use for a Marine ACE are based on data from Amphibious Group Three [Ref. 28]. The transit and presence phases approximate one-half the combat phase JP-5 usage [Ref. 8: p. 22] for the CVW and ACE. This allows for heavy work-ups in addition to normal training and maintenance. To make the problem easier to model, the maximum JP-5 figure for the battle group will be the summation of the JP-5 carried aboard the CV/CVN, the LHA (if involved in scenario) and the cargo JP-5 aboard the AOE. The escorts with embarked LAMPS detachments will not be factored into the overall JP-5 capacity or daily usage rate. The JP-5 usage of an ASW helicopter operating from a DD is negligible when compared to JP-5 usage rate for a CV or CVN. Table 6 shows the maximum JP-5 capacities for the for the aircraft carriers and the LHA while Table 7 shows the battle group's daily JP-5 usage rates for each scenario.

Table 6 JP-5 Storage Capacities (Gallons)

Ship Class	Maximum Capacity
CVN-68	2,400,000
CV-63	1,500,000
LHA	300,000

Table 7 JP-5 Usage Rates (Gallons per Day)

Scenario	Maximum JP-5 Available	Transit Phase	Presence Phase	Combat Phase
Scenario 1	5,212,225-7,493,687	106,250	106,250	212,500
Scenario 1A	4,312,225-6,593,687	106,250	106,250	212,500
Scenario 1B	5,512,225-7,793,687	167,750	167,750	335,500
Scenario 1C	4,612,225-6,893,687	167,750	167,750	335,500

Note: JP-5 figures show possible range of JP-5 based on AOE-6 cargo fuel tank configuration.

3. Ordnance

At the beginning of the scenario, the AOE will moving to a Naval Magazine to conduct a weapons onload. One important aspect of loading ordnance on a CLF ship is that the main constraints to loading are volume, measured in cubic feet, and compatibility. However, expenditure rates are usually measured by weight (tons) of the ordnance spent. The model to load weapons will look at all constraints, including weight and volume, while the second model that tracks commodities available to the battle group on a daily basis, will track ordnance in tons. For the AOE-6 class, the designed maximum ordnance capacity is 1,800 tons [Ref. 5: p. B-1]. This design capacity does not include a stow factor.

While the AOE represents a portion of the ordnance carried in the battle group, aircraft carriers carry even larger quantities of ordnance. Each ship in the battle group will also be fully loaded prior to sailing. The maximum ordnance available for any scenario will be the summation of all the individual ship weapons capacities as well as the cargo ordnance available from the AOE. Once the AOE-6 onload is complete and the battle group has left port, ordnance will be expended as a single commodity measured in tons. Table 8 provides a look at the ordnance tonnage available for each ship class in the battle group. Table 9 provides a look at the total ordnance tonnage when the battle group is fully armed for each scenario as well as the planned expenditure rates for each phase of the operation. The ordnance figures for the ship classes are taken from the Unclassified TACLOGS Database [Ref. 27] and are estimates based upon the weapon weights of a notional loadout.

The AOE(V) study [Ref. 25] and the 1993 thesis by LT. Reeger [Ref. 8] also provide guidance for the daily rate of ordnance expenditures. The usage rate for this model will be 10 tons per day during the presence phase and 100 tons of ordnance per day during the combat phase [Ref. 8: p 23, Ref. 25: p.22]. For the combat phase, this is half the strike ordnance used per carrier per day during the Vietnam War and reflects the preponderance of "smart" weapons in the current ordnance inventory [Ref. 8: p.23]. This expenditure rate will not change when the amphibious forces join the battle group. This assumes that the ordnance used by the Marine ACE will be supplied by the LHA and that separate arrangements have been made to rearm LHA.

Table 8 Ship's Ordnance Capacity

Ship Class	Total Tonnage of Ordnance
CVN-68	2,500
CV-63	2,400
CG-47	160
DDG-51	150
DDG-993	115
DD-963	126
AOE-6	5

Note 1: AOE-6 figure does not include cargo ordnance.
Note 2: Amphibious forces will not be included in ordnance figures.

Table 9 Max Ordnance Availabilities (Tons) and Expenditure Rates (Tons per Day)

Scenario	Maximum Available	Transit Phase	Presence Phase	Combat Phase
Scenario 1	5,016	0	10	100
Scenario 1A	4,916	0	10	100
Scenario 1B	5,016	0	10	100
Scenario 1C	4,916	0	10	100

Table 10 is taken from Reeger's thesis [Ref. 8] and provides the conversion factors used when converting commodities from weights to volumes and vice-versa. These figures are applicable to stores and commodities as well as ordnance.

Table 10 Standard Conversion Factors for Calculating Shipboard Cargo Volumes [From Ref. 8]

Cargo Type	**Cargo Usable Volume Conversion Tables**
Ordnance:	1 CU. FT. Usable = L. Tons (2,240 LBS)
100% AMMO	1 CU. FT Usable = .0133 L. Tons
50% Missiles/ 50% Ammo	1 CU. FT Usable = .0080 L. Tons
100% Missiles	1 CU. FT Usable = .00266 L. Tons
DRY STORES	1 CU. FT Usable = .00756 L. Tons

4. Stores

Reeger's thesis provides a consolidated logistics planning factor of 9.62 pounds of stores per day per man [Ref. 8: p. 24]. Table 11, also from LT. Reeger's thesis, shows a breakdown of the logistics factors by class.

Table 11 Consolidated Logistics Planning Factors [from Ref. 8]

Class/ Subclass	**Description**	**Planning Factor (Afloat) (lbs/man/day)**
I	Subsistence	5.62
IIE	General Supply	2.45
IIF	Clothing	.09
IV	Construction	.09
VI	Personal Demand	.63
VII	Major End Items	.05
VIII	Medical Material	.05
IX	Spares and Components	.64
	TOTAL	9.62

Using this planning figure, the daily stores usage rate will be determined by summing the total number of personnel in the battle group and multiplying by 9.62 pounds. This factor will not change during the three phases of the operation. Table 12 shows the manning for each ship class involved in the scenarios. These figures are taken from Jane's Fighting Ships 1994-1995 [Ref. 26] and the OA-4611 Logistics in Naval Warfare Paper Proposal [Ref. 24]. The maximum available stores commodity level is found by taking the daily usage rate and multiplying by 30 and adding the stores capacity of the AOE. To arrive at the number 30, it is expected that each ship would be self sustaining for a minimum period of 30 days. Table 13 summarizes the maximum stores commodities available for each scenario as well as the daily usage rates for the three phases.

Table 12 Ship's Manning and Daily Stores Requirements

Ship Class	**Manning**	**Daily Requirement (TONS)**
CVN-68	4,723	20.28
CV-63	4,273	18.35
CG-47	450	1.93
DDG-51	334	1.43
DDG-993	334	1.43
DD-963	290	1.24
AOE-6	660	2.83
LHA	559	2.40
LPD-4	466	2.00
LSD-41	335	1.44
MEU	3,000	12.80

Note: Embarked Navy Units (CVW etc) are counted as part of ship's manning while the Marines are counted under MEU.

Table 13 Daily Stores Usage Rate

Scenario	Maximum Available (Tons)	Daily Usage Rate (Tons)	Number of Days of Supply (MAX/USAGE)
Scenario 1	1,658.42	32.5	51.03
Scenario 1A	1,600.52	30.57	52.36
Scenario 1B	2,217.92	51.14	43.37
Scenario 1C	2,159.72	49.21	43.89

5. Summary of Data

Each of the four previous sub-sections detailed for the reader the process by which the daily usage rate and maximum quantity of each particular commodity was found for a particular battle group. Table 14 provides a complete summary of the commodity usage rates for the battle group for each phase in each scenario.

Table 14 Scenario Data Summary

		Scenario 1	Scenario 1A	Scenario 1B	Scenario 1C
Battle Group		CVNBG 6 Escorts 1 AOE-6	CVBG 6 Escorts 1 AOE-6	CVNBG 6 Escorts 1 AOE-6 1 ARG	CVBG 6 Escorts 1 AOE-6 1 ARG
Daily DFM Usage Rate (Gal/day)	Transit	327,024	448,968	321,074	402,482
	Presence	188,905	250,715	248,559	286,599
	Combat	227,945	309,353	286,599	369,007
Daily JP-5 Usage Rate (Gal/day)	Transit	106,250	106,250	167,750	167,750
	Presence	106,250	106,250	167,750	167,750
	Combat	212,500	212,500	335,500	335,500
Daily Ammo Usage Rate (Tons/day)	Transit	0	0	0	0
	Presence	10	10	10	10
	Combat	100	100	100	100
Daily Stores Usage Rate (Tons/day)	Transit	32.5	30.57	51.14	49.21
	Presence	32.5	30.57	51.14	49.21
	Combat	32.5	30.57	51.14	49.21

C. SCENARIO ASSUMPTIONS

Several assumptions are made about the scenario in order to isolate the AOE. The goal here is to assure that all logistics support for the battle group flows through the AOE.

* Forward support basing (ALSS) is fully operational.
* Sea and airlift is available to fully supply the ALSS from the United States .
* Enough single product shuttle ships are available to move commodities from the ALSS to the battle group station ship.
* CONSOL operations will occur when any single commodity reaches the minimum level for the battle group. All commodities will then be replenished to the maximum capacity for the battle group. The single commodity shuttle ships will all load, transit, UNREP and return to port simultaneously.
* Every ship will start the scenario fully fueled, armed and resupplied, including the AOE.
* The ARG will consist of one LHA, one LPD and one LSD with an embarked Marine Expeditionary Unit (MEU) of 3,000 Marines, six Harriers, and 26 Marine helicopters embarked.
* The AOE will supply the ARG with fuel and provisions only.

IV. SURVEY

The purpose of this survey is to demonstrate a method of prioritizing the relative value for each type of ordnance utilized in the survey. Only by assigning a certain benefit, or "utility", to each weapon, can an "optimal" load list, or solution be generated by a linear program. A primary focus of this thesis is the development of a model that will load ordnance aboard a ship, based on the physical characteristics of the ship and the ordnance. This thesis is not however, focused on the optimal method of finding the relative benefit for each ordnance type. As such, decreasing marginal returns are not utilized in this model. This fact is partially compensated for by assigning a minimium and maximum number of each weapon that can be loaded.

The loadout for any ammunition carrying ship is shown on a document called a tailored load list. This document lists the variety and quantity of the various products carried by the ship [Ref. 23]. The tailored load list used as a planning aid in this thesis is the USS Seattle's tailored load list for her 1995 deployment [Ref. 23]. Remembering that the main function of the AOE is to support the CVBG, including the embarked air wing, a load planning conference is held to determine which weapons and in what quantity, are to be carried by the AOE. The main participants in the conference are the aircraft carrier's ordnance officers, the deploying battle group commander's and air wing's strike operations people and the surface type commander [Refs. 15 and 22]. Their job is to develop a clear concise list of weapons they desire the AOE to carry in order to resupply the CVBG. The surface type commander is involved to ensure that adequate resupply is available for the escorts traveling with the carrier.

Thanks in large part to the Persian Gulf War, models based on recent experience exist to accurately predict ordnance expenditures during combat operations. However, in today's fast changing world, a deploying battle group has no way of knowing what type of operation they will become involved in. This means the CVBG must carry a variety, over 300 line items, of ordnance and accompanying accessories. For the purpose of this survey, 21 weapons were selected from a current AOE tailored load list [Ref. 23] for use in the given scenario. One consideration given to what ordnance will be included on the survey list is that weapons that could not be loaded, reloaded, fired or transferred at sea would not be included. Such important weapons as Tomahawk cruise missiles, ship launched (canister) Harpoon anti-ship missiles and vertically launched SM-2 missiles fall into this category. The second, subjective, consideration is that the weapon must have well known employment features to a "majority" of aviation and surface warfare qualified naval officers polled in the survey.

As stated previously, the goal of this survey is to develop a method of prioritization. This is done by establishing a minimal ordnance loadout, that is a minimum number of each of the 21 weapon types chosen for the survey, aboard the AOE-6 to respond to the most likely contingencies a deploying CVBG would encounter. This minimal loadout is in effect the minimum number of each weapon that will be carried aboard the AOE and is transparent to the survey respondent. This minimal ordnance level is determined randomly by the modeler, in this case the author, to force the AOE to carry a minimum of each of the 21 weapon types. It does not, nor is it intended, to reflect a given percentage of the AOE loadout. To attempt to try to pre-load the AOE with a given percentage, based solely on the limited number of weapon types would be unrealistic. A warfare qualified naval officer is then provided a combat scenario in which that officer will determine which weapons that individual feels would be most useful given the particular scenario. A maximum level for each weapon is set to prevent the model from filling the AOE with a large number of high priority weapons. Should the mission tasking change to an open ocean ASW threat, the minimum (and maximum) levels for weapons such as MK-46 and Sonobouys would rise, while the minimum (and maximum) level for

Hellfire missiles may drop. The process is modeled after the load conference, with one person, the author, playing the role of the conference participants. This method of setting minimums and maximums also replicates the power that Fleet and CVBG commanders have to modify load lists.

The naval officer's survey responses are used to assign weights or values to the different types of ordnance. The ordnance loading model will then provide an optimum load list, based on the ordnance values, detailing the number of each weapon type to load and the storage area to place the weapon in, staying within the volume, weight and compatibility constraints of the AOE-6. Naval Weapons Station, Earle, NJ still uses the pencil and paper method of determining where on the ammunition ship to place ordnance to meet all the constraints involved in ordnance storage [Ref. 15].

The loading of ordnance on the ship accomplished by the first computer model will look at five factors. Four of the factors, weight, volume, compatibility and required accessories are already determined. The fifth factor is benefit. This survey will scale each ordnance type of the 21 in the survey and give a scaled benefit for that ordnance type. These scaled benefit values will then be transformed to an ordinal scale, from 1 to 100 to be used in the objective function of the model. The objective function for this model will be to maximize the benefit to the battle group of the entire CLF ship weapon loadout. This survey will afford the individual officers the opportunity to use their experience and judgment in deciding which ordnance types are most favorable to have for immediate resupply of the battle group.

A. SURVEY METHODOLOGY

The survey instructions, Appendix E, and the survey, Appendix F, were designed to provide a method to determine a prioritization of ordnance to be loaded in the ammunition holds of the AOE-6 class ship. The survey format is based one developed by Guadalupe [Ref. 12], and used by Rowland [Ref. 9]. The forms were distributed evenly between officers at NPS and officers in current fleet operational billets. The goal was to survey officers with backgrounds in carrier battle group operations. Individuals such as carrier air wing pilots and naval flight officers as well as surface warfare officers were sought. Fleet surveys were sent to aircraft carriers, carrier air wings, commanding officers of cruisers and destroyers and various aircraft squadron commanding officers.

A categorical method (developed by Lindsay [Ref. 11] and used by Rowland [Ref. 9]) was employed to elicit preferences between the different ordnance types. The categorical method also makes it easy for both the person doing the survey and grading the survey to use. The categories used to prioritize the ordnance were

1. very low,
2. low,
3. medium,
4. high, and
5. great contribution to the CVBG mission accomplishment.

1. Ordnance

The survey form listed 21 types of ordnance for evaluation. The person responding to the survey placed a mark in the appropriate category. While a tailored load list may have over 300 line items, the list was pared down by choosing ordnance that could be used and loaded while remaining at sea and choosing mostly threat ordnance for evaluation.

B. SURVEY QUESTIONNAIRE STATISTICS

A total of 100 survey forms were sent out, of which 77 were completed and returned. The Survey Information Questionnaire, Appendix G, provided information about the officer completing the survey as well as comments about the survey:

The 77 returned surveys included inputs from 53 lieutenants, 15 lieutenant commanders, eight commanders and one captain. By designator, the breakdown included 38 surface warfare officers, 19 pilots and 20 naval flight officers. The average number of years spent on active duty in the survey was 10.6 years, with an average of less than one year of staff duty.

The comments concerning the survey indicate that the basic scenario was understandable. The majority of specific comments came from fleet aviators and naval flight officers. The main focus of these comments centered on the desire for more detailed enemy orders of battle and information on specific targets. The most common comment was for more information on the ratio of "hard" targets to "soft" targets. In reality, more detailed information will be available on specific targets so this comment is a fair one. One other respondent desired more information about the air wing composition.

Of the 21 weapons rated in the survey, ASROC, MK 46 torpedoes and MK 60 Captor mines were the weapons that survey takers wanted to drop from the weapons load list. One specific comment was to allow land based P-3 and B-52 aircraft conduct offensive mining if necessary. Most officers felt that the use of rail launched ASROC is now limited to only one class of ship (DDG-993) so this weapon could be dropped.

The most common weapon that survey takers wanted added to the survey weapons list was the Advanced Medium Range Air to Air Missiles (AMRAAM). This weapon is actually an Air Force design that is currently being added to the Navy arsenal. While not part of the USS Seattle tailored load list, it is anticipated that it will soon become part of the load list for future deploying battle groups. Other weapons mentioned to add included laser guided bombs, which actually are not weapons, but a fin set and guidance package for the MK 80 series bombs, MK 50 torpedoes (to replace MK 46 torpedoes), Gator mines, SLAM missiles and 25 MM Chain Gun ammunition.

The majority of comments made were very constructive. As expected, the most detailed comments came from officers with a strike warfare background. These officers were very informative on the detailed process a strike operations planner goes through prior to launching aircraft. They were very concerned with the level of detail of the survey and felt they had to make too many assumptions with their answers. Again, it must be remembered that the focus of this project is to develop a model to load ordnance, not develop the best method of determining weapon utility. In an actual scenario, the strike mission planners will have adequate time to develop a more detailed prioritization method to work with.

C. RAW FREQUENCY DATA

Table 15 shows the results for survey responses, with the weapon type being listed down the left column and the contribution categories listed across the top:

Table 15 Raw Frequency Data

Weapon Type	Very Low	Low	Medium	High	Great
Sidewinder	9	18	24	25	1
Sparrow III	7	16	38	15	1
Phoenix	29	17	20	8	3
SM-2 (Rail)	11	26	18	18	4
Chaff	4	8	15	32	18
Sonobouys	4	9	30	28	6
Walleye	2	18	25	25	7
HARM	0	8	25	21	23
Rockeye	0	5	38	22	12
Maverick	5	10	22	29	11
Hellfire	11	15	33	16	2
Harpoon	10	26	23	10	8
CIWS ammo	3	14	18	30	12
Sea Sparrow	4	28	22	18	5
MK 60 mine	37	20	16	3	1
MK 46 Torpedo	12	15	35	13	2
ASROC (Rail)	32	21	19	5	0
2000 lb. bomb	2	17	22	29	7
1000 lb. bomb	1	6	22	30	18
500 lb. bomb	2	11	20	29	15
5' 54 ammo	0	12	26	20	19

One major weakness of this survey method is that the opinion of a surface warfare qualified lieutenant with six years on active duty carries the same weight as an aviation qualified, strike warfare experienced captain with 24 years on active duty, even when evaluating the benefit of 500 and 1,000 pound bombs as compared to a Walleye or Maverick.

D. SCALING OF SURVEY RESULTS

1. Interval Scale Construction

The data collected from the survey was scaled using the categorical ratings and the Lindsay ten-step procedure for obtaining scale values from such categorical judgements. This method was selected based upon its successful use in a similar study by Rowland [Ref. 9]. The Lindsay ten-step procedure [Ref. 11] constructs an interval scale that includes both instances and bounds between categories. By showing the bounds between the categories, descriptive benchmarks appear on the final scale. For this study, instances are the different ordnance types which make up the rows of the frequency array and the categories of contribution to mission make up the columns as shown in Table 17.

Typically, five categories are used when employing the Lindsay ten-step method. No assumptions are made about the relative interval sizes. In the general method of successive intervals, it is assumed, either explicitly or implicitly, that the category boundries are fixed throughout the experiment [Ref. 32: pp. 208-209]. Each category is understood to be a mutually exclusive set of successive intervals which collectively exhaust the continuum [Ref. 11: p.1]. The ten-step method does however require four basic assumptions [Ref. 11]:

1. The rater's judgements about the scale value of an instance i can be expressed as a normally distributed random variable with mean μ_j and variance $\sigma^2{}_j$.

2. Rater's view the continuum of values for instances as categories that are broken into successive intervals, each having an upper bound. The rater's judgements about the category's upper bound is also expressed as a normally distributed random variable. Category j has a normally distributed random variable with mean μ_j and variance σ^2_j.

3. The rater's judgement about the scale values of instances are stochastically independent random variables that have a correlation coefficient of zero for all pairs i and j.

4. All category bounds have the same variance, that is, $V^2_j = c$ for all j.

2. Ten-Step Procedure for Obtaining Scale Values

The ten steps of the Lindsay procedure are shown below. This method yields scaled numerical data from categorical responses such as the benefit of different types of ordnance. The scaled data derived from this procedure will then be used as input into the objective function of the ordnance loading model.

1. Arrange the raw frequency data in a table F_{ij} where the rows are instance i and the columns are categories j. The columns should be arranged in ascending order of category value, so that the last column to the right represents the most favorable category.

2. Compute relative cumulative frequencies for each row, and record these in a new table P_{ij} where P_{ij} is the proportion of raters judging instance i in or below category j. The values in the right hand column of P_{ij} will always be one and may be omitted for computational purposes.

3. Compute the Z_{ij} array by treating the P_{ij} values as leftward areas under a Normal (0,1) curve and find the Z values for these areas in a normal or Gaussian distribution table.

4. Compute the row average $\mathbf{Z_i}$ for each row i in the Z_{ij} array.

5. Compute the column average b_j for each column j in the Z_{ij} array. The b_j column averages are the upper bound values of category j on the scale.

6. Compute the grand average **b** of all the values in the Z_{ij} array. This is done by averaging the column averages of b_j.

7. Compute the sum of squares for the row differences.

$$B = \Sigma (b_j - \mathbf{b})^2 \qquad \text{for all } j$$

8. Compute the sum of squares for the row differences.

$$A_i = \Sigma (Z_{ij} - \mathbf{Z_i})^2 \qquad \text{for all } j$$

9. Compute $\text{sqrt}(B/A_i)$ for each row to give an estimate of $\text{sqrt}(\sigma^2_i + c)$.

10. Compute $S_i = \mathbf{b} - \mathbf{Z_i} * [\text{sqrt}(B/A_i)]$ for each row i. The S_i values are the scale values of the instances, and are on the same interval scale as the category bounds b_j. A linear transformation $Y = \alpha + \beta x$, $\beta > 0$ may be performed to move the scale to any position desired. The same transformation must be used to move the instance values and the category bounds.

3. Scale Values from the Survey Data

The preceding ten-step procedure was applied to the raw data set comprised of the officer group surveyed. Appendix H demonstrates the detailed step by step procedure for converting the officer's survey responses to numerical data. The purpose of this scaling is to take the categorical survey results, develop scaled weights, or values, for each of the weapon types, and transform the scaled value into usable, easy to understand relative values. Tables 16 shows the final results of the ten-step procedure. The far right column, the transformed value, is the benefit, or utility, of each weapon that will be used in the computer model.

If the reader is interested in the process of going from the scaled value to the transformed value, a detailed description is provided in Appendix H. Figure 1 provides an overview of the results shown in Table 16.

Table 16 Scaling Results for the Ordnance Survey

Problem 1	Scaled Value	Transformed Value to Problem 5 Scale
Rockeye	-.274	53.3
HARM	.098	62.9
1000 lb bomb	.158	64.5
upper bound, high	.761	80.0
upper bound, medium	-.128	57.1

Problem 2	Scaled Value	Transformed Value to Problem 5 Scale
MK 46	-.045	43.0
Sidewinder	.199	47.9
SM-2	-.014	43.6
Hellfire	-.074	42.4
Harpoon	.021	44.3
upper bound, medium	.662	57.1
upper bound, low	-.197	40.0
upper bound, very low	-1.095	22.1

Problem 3	Scaled Value	Transformed Value to Problem 5 Scale
Phoenix	.228	34.4
ASROC	-.016	27.5
MK 60 mine	-.122	24.6
upper bound, low	.427	40.0
upper bound, very low	-.208	22.1

Problem 4	Scaled Value	Transformed Value to Problem 5 Scale
Sea Sparrow	-.103	49.1
Walleye	.416	58.1
2000 lb bomb	.497	59.5
Sonobouys	.563	60.7
Sparrow III	.017	51.2
upper bound, medium	.357	57.1
upper bound, low	-.628	40.0

Problem 5	Scaled Value	Transformed Value
Chaff	.157	64.1
Maverick	-.117	58.0
5' 54 ammo	.054	61.8
CIWS ammo	-.113	58.1
500 lb bomb	.039	61.4
upper bound, high	.873	80.0
upper bound, medium	-.156	57.1
upper bound, low	-.924	40.0

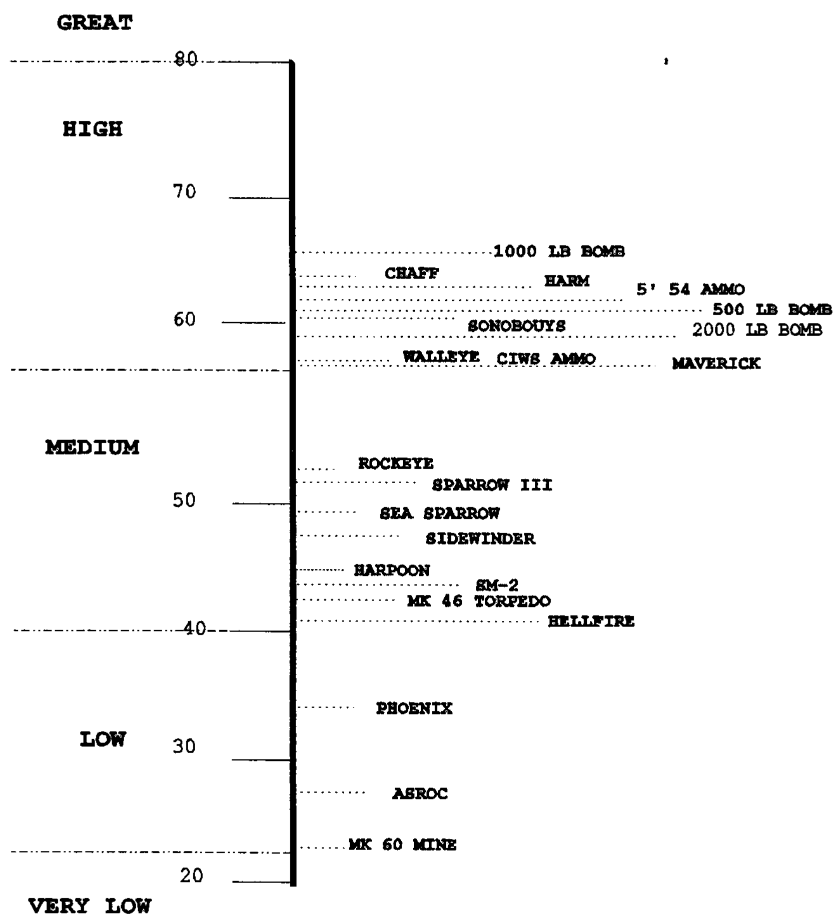


Figure 1 Transformed Survey Results

V. MODEL DEVELOPMENT

A. ORDNANCE LOAD MODEL

1. Methodology

The first step in developing the optimal load list model is to decide how many weapon types are to be loaded aboard the CLF ship. For a true AOE tailored load list, the number of different weapon types is over 300! An example of this process for this thesis would be the Harpoon anti-ship missile. There are currently three versions of this missile, rail launched from a Perry class frigate, the canister launched version, and the air launched version. Since the escorts did not include a frigate, the rail launched Harpoon was not included. Since the canister launched version fails the criteria of being able to reload and fire without entering port it was also excluded from the model. Other weapons such as 5 inch 54" gun ammunition or Sonobouys come in many different variations. For this model all 5 inch ammunition was lumped into one weapon type. The modeler must also decide what benefit each weapon will bring to the battle group. The second step is to investigate the physical characteristics of each selected ordnance type, determine if additional accessories would be required to employ the weapon, the weights and volumes of each of these accessories, and the compatibility type of each weapon. The third step is to look at the actual size and number of ordnance storage areas on the ship to be loaded. The fourth step is to gain an awareness for the various constraints involved in loading ordnance aboard a ship. Factors such as ship stability, deck stress, available storage volume and ordnance compatibility constraints must be taken into account if the AOE that is to be loaded correctly and safely. For this model, steps one and two were completed in Chapter IV, while steps three and four were completed in Chapter II.

In the final formulation, step one provides the information for developing the sets, or indices. Steps two and three provide the information that will make up the input data. Step four provides the necessary information to be used as constraints in the formulation equations.

2. Model Assumptions

The major assumption of this model is that all equations relating the objective function to the constraint are linear. This assumes that for any given quantity X, of weapon type W, multiplied by the benefit as described in Chapter IV, is X times more valuable to the battle group then just one weapon with the same benefit. Other assumptions used in the design of this model include:

1. The constraints of this linear program model consist of volumes, weights, deck stress, ship stability and weapon storage compatibility.
2. As described in Chapter IV, a minimum number of each weapon must be carried aboard the AOE. Other weapons will be loaded as the various constraints permit.
3. There are sufficient quantities of weapons, personnel, MHE, stowage gear and time to get the ordnance stored safely and securely aboard the AOE. Ordnance stockpiles are sufficient to load up to the maximum level, described in Chapter IV, of each weapon type.
4. All ordnance loaded aboard the AOE can be transferred, reloaded, and used, without entering port by a minimum of one ship in the battle group.
5. The program will specify in which hold and on which deck the ordnance item should be stowed, but not where on the deck it should be placed (an example would be the 2nd hold, 1st Platform). Either ship's company or the accountable Naval Weapons Station will determine the exact storage configuration based on the model generated load list.
6. All ordnance, including inert ordnance, will be stored in designated ordnance storage areas aboard the ship.

3. Description

Indices

In this model five indices are utilized. W represents a weapon type. For this model, the set W includes the 21 weapons as described in Chapter IV. A second set representing the different weapon types is also included, called WP, and is simply an alias for W. The set AC represents a set of weapon accessories that need to be installed on the weapons in set W to employ them in combat. The set C represents the compatibility type that are used to classify each weapon in set W. The final set D, represents the number of available storage decks on the ship to be loaded.

Input Data

Input data, or parameters, list the given information with which the model starts. The following describe each parameter in detail.

M = Large scalar number.

Vol_W = Each pallet or container of ordnance a combatant receives is called a unit round. This parameter shows the volume of each weapon unit round in cubic feet.

$ACCVOL_{AC}$ = Volume of each accessory such as Harpoon wings and fins in cubic feet. While these accessories take up weight and volume on the AOE, they provide no additional benefit to the battle group, yet they must be carried if a weapon that requires an accessory is loaded.

WT_W = Weight of weapon unit load in lbs divided by 1,000.

$ACCWT_{AC}$ = Weight of accessory unit load in lbs divided by 1,000.

$BENEFIT_W$ = Based upon the prioritization method described in Chapter IV, each weapon in set W received a scaled benefit value. This benefit value will be used in the objective function to optimize the AOE loadout to provide the overall highest benefit to the CVBG of all the weapons carried on the AOE.

$COMP_{W,C}$ = A binary variable that shows the compatibility type of each weapon in set W. Compatibility is a function of the type of warhead and fuel that is stored inside the weapon casing.

$CUBE_{D}$ = This parameter is the maximum volume or usable "bale" available aboard the AOE for each storage area in set D. This area is measured in cubic feet.

$STRESS_{D}$ = The second design constraint on loading any stores on a ship is the maximum deck stress. This is normally measured in pounds per square foot. For this model, stress will be measured as the area of deck times in square feet, multiplied by the allowable stress and then divided by 1,000 in pounds.

$MINWEAP_{W}$ = Minimum number of weapon unit loads of set W to load aboard the AOE. This number will normally be dictated by the Battle Group Commander.

$MAXWEAP_{W}$ = Maximum number of weapon unit loads of set W to load aboard AOE.

$REQACC_{W,AC}$ = Details, by a one or a zero (only 1s are shown) which weapons require accessories to be employed in combat.

$MIX_{C,C}$ = A symmetric binary table from the Code of Federal Regulations [Ref. 3] that shows which weapons with compatibility type C can be stored with what other weapons of compatibility type C.

Derived Data

"Derived data includes information relevant to the model that is developed prior to actually solving the problem" [Ref. 8: p.14].

$WEPCMP_{W,WP}$ = A table that shows, by a 1 or a 0, if any one weapon in the survey can be stored with another. It is found by doing using $COMP_{W,C}$ and $MIX_{C,C}$ in a double loop to investigate each possible weapon storage combination and determine if that combination is legal.

Variables

"Variables are the entities whose values are generally unknown until the model has been solved" [Ref. 10: p. 81].

$STORES_{W,D}$ = When the program is solved, this variable will show how many unit loads of each weapon type W, are stored on storage deck D. To reduce the complexity of the problem, this is a positive variable vice an integer variable.

$ACC_{W,AC,D}$ = For each weapon W, that requires an accessory AC, this variable will show on which deck D it will be stored.

$YSTORES_{W,D}$ = A binary variable used in the compatibility constraints. Will have a value of 1 if weapon type W stored on deck D and 0 if no weapon type W on deck D.

Z = Total benefit of ordnance loadout.

Equations

The equations section of the model details the objective function and the constraints. For this model, the objective function determines the surrogate MOE and the constraints ensure that the model will load the ship in a safe, logical manner.

(EQ1A) $Z = \Sigma_D [\Sigma_W (BENEFIT_W * STORES_{W,D})]$

The goal of the objective function is to load the AOE in such a manner as to maximize the usefulness or "benefit" for the CVBG. By finding the maximum benefit, the model is forced to look at all possible ordnance loadout combinations to ensure the best one is selected.

(EQ2A) $\Sigma_D STORES_{W,D} >= MINWEAP_W$ for all $_W$

This equation instructs the model to ensure that a minimum of each weapon is to be loaded aboard the AOE.

$$\text{(EQ3A)} \quad \Sigma_{D}\ STORES_{W,D} <= MAXWEAP_{W} \qquad \text{for all}\ _{W}$$

This equation instructs the model to ensure that no more then a certain number of each weapon is to be loaded aboard the AOE.

$$\text{(EQ4A)} \quad \Sigma_{W}\ (VOL_{W} * STORES_{W,D}) +$$

$$\Sigma_{AC}\ [\Sigma_{W\ st\ REQACC\ W,AC > 0}\ (ACCVOL_{AC} * ACC_{W,AC,D}) <= CUBE_{D} \quad \text{for all}\ _{D}$$

This equation instructs the model to account for the upper bound of cubic storage feet available on each ordnance storage deck. The cubic feet available on each deck must be greater then the combined volumes of all of the weapon and accessory unit loads that are stored on that deck.

$$\text{(EQ5A)} \quad \Sigma_{W}\ (WT_{W} * STORES_{W,D}) +$$

$$\Sigma_{AC}\ [\Sigma_{W\ st\ REQACC\ W,AC > 0}\ (ACCWT_{AC} * ACC_{W,AC,D}) <= STRESS_{D} \quad \text{for all}\ _{D}$$

This equation instructs the model to account for the upper bound of allowable weight (or deck stress) for each ordnance storage deck. The strength of the deck must be greater then the combined weights of all of the weapon and accessory unit loads that are stored on that deck.

$$\text{(EQ6A)} \quad \Sigma_{D}\ ACC_{W,AC,D} >= REQACC_{w,ac} * \Sigma_{D}\ STORES_{W,D} \qquad \text{for all}\ _{W,AC}$$

This equation instructs the model to ensure that if any weapon that requires an accessory to be employed in combat, that accessory is also loaded on the AOE.

$$\text{(EQ7A)} \quad \Sigma_{W}\ (WT_{W} * STORES_{W,1}) + \Sigma_{w}\ (WT_{W} * STORES_{W,2}) + \Sigma_{w}\ (WT_{W} * STORES_{W,3}) >=$$

$$\Sigma_{W}\ (WT_{W} * STORES_{W,4}) + \Sigma_{W}\ (WT_{W} * STORES_{W,5}) + \Sigma_{W}\ (WT_{W} * STORES_{W,6}) +$$

$$\Sigma_{W}\ (WT_{W} * STORES_{W,7})$$

This equation requires the model to put the more weight forward, in hold 1, than in hold 2.

$$(EQ8A)\ \Sigma_W\ (WT_W * STORES_{W,4}) + \Sigma_W\ (WT_W * STORES_{W,5}) + \Sigma_W\ (WT_W * STORES_{W,6}) + \Sigma_W\ (WT_W * STORES_{W,7})\ >= \Sigma_W\ (WT_W * STORES_{W,8}) + \Sigma_W\ (WT_W * STORES_{W,9}) + \Sigma_W\ (WT_W * STORES_{W,10}) + \Sigma_W\ (WT_W * STORES_{W,11})$$

This equation requires the model to put more weight in hold 2 than in hold 3. Equations 8A and 9A together ensure the ship is loaded with the most weight forward, closest to the bow.

$$(EQ9A)\ \Sigma_W\ (WT_W * STORES_{W,3}) + \Sigma_W\ (WT_W * STORES_{W,6}) + \Sigma_W\ (WT_W * STORES_{W,7}) + \Sigma_W\ (WT_W * STORES_{W,10}) + \Sigma_W\ (WT_W * STORES_{W,11}) >= \Sigma_W\ (WT_W * STORES_{W,1}) + \Sigma_W\ (WT_W * STORES_{W,2}) + \Sigma_W\ (WT_W * STORES_{W,4}) + \Sigma_W\ (WT_W * STORES_{W,5}) + \Sigma_W\ (WT_W * STORES_{W,8}) + \Sigma_W\ (WT_W * STORES_{W,9})$$

This equation ensures that the more weight will be stored in the lower two levels than in the upper two levels.

$$(EQ10A)\ \Sigma_W\ (WT_W * STORES_{W,2})\ +\ \Sigma_W\ (WT_W * STORES_{W,5}) + \Sigma_W\ (WT_W * STORES_{W,9})\ >= \Sigma_W\ (WT_W * STORES_{W,1})\ +\ \Sigma_W\ (WT_W * STORES_{W,4}) + \Sigma_W\ (WT_W * STORES_{W,8})$$

This equation ensures that the least amount of weight will be in the highest storage level of the ship, the second deck. Together equations 9A and 10A ensure that the most weight is stored lowest on the ship.

$$(EQ11A)\ YSTORES_{W,D} * M >= STORES_{W,D} \qquad \text{for all}_{\ W,D}$$

This equation simply states that if a weapon W, is stored on deck D, then $YSTORES_{W,D}$, being a binary variable, must take a value of 1. This equation is designed to be used with equation 12A to model weapon compatibility.

(EQ12A) $STORES_{WP,D} <= M * (1 - YSTORES_{W,D})$ for all $_{W,WP,D}$

st $WEPCMP_{W,WP} = 0$

This equation states that if $WEPCMP_{W,WP} = 0$, then the two weapons, W and WP will not be stored together because they are incompatible. This constraint is only utilized when $WEPCMP_{W,WP} = 0$.

4. Formulation

Indices

W	=	Weapon type (Sidewinder, 2,000 lb. bomb, etc.).
D	=	Number of storage decks on ship.
AC	=	Weapon accessory (Wings, Fins, starter kits, etc).
C	=	Weapon compatibility type.
WP	=	A second set representing weapon type.

Input Data

M	=	Large scalar number.
Vol_W	=	Volume of each weapon unit round in cubic feet.
$ACCVOL_{AC}$	=	Volume of each accessory in cubic feet.
WT_W	=	Weight of weapon unit load in lbs divided by 1,000.
$ACCWT_{AC}$	=	Weight of accessory unit load in lbs divided by 1,000.
$BENEFIT_W$	=	Relative scaled value of each weapon as compared to other weapons in scenario.
$COMP_{W,C}$	=	A binary variable representing the compatibility type of each weapon.
$CUBE_D$	=	Usable area for storage on each deck in cubic feet.
$STRESS_D$	=	Area of deck times allowable stress divided by 1,000 in pounds.
$MINWEAP_W$	=	Minimum number of weapon unit loads(from Chap. IV).
$MAXWEAP_W$	=	Maximum number of weapon unit loads(from Chap. IV).
$REQACC_{W,AC}$	=	When necessary, fill the requirement to bring an accessory for a certain weapon.
$MIX_{C,C}$	=	Weapon storage compatibility table.

Derived Data

$WEPCMP_{W,WP}$ = Table indicating which weapons are legally allowed to be stored with which weapons.

Variables

$STORES_{W,D}$ = Number of unit loads of weapon type W, stored on deck D.

$ACC_{W,AC,D}$ = Number of unit loads of accessory AC, stored on deck D.

$YSTORES_{W,D}$ = 1 if weapon type W stored on deck D, 0 if no weapon type W on deck D.

Z = Total benefit of ordnance loadout.

Equations

The formulation is then:

Maximize:

(EQ1A) $Z = \Sigma_D [\Sigma_W (BENEFIT_W * STORES_{W,D})]$

Subject to:

Minimum and maximum weapon unit load constraints:

(EQ2A) $\Sigma_D STORES_{W,D} >= MINWEAP_W$ for all $_W$

(EQ3A) $\Sigma_D STORES_{W,D} <= MAXWEAP_W$ for all $_W$

Weight and volume constraints of ship:

(EQ4A) $\Sigma_W (VOL_W * STORES_{W,D}) +$

$\Sigma_{AC} [\Sigma_{W \text{ st } REQACC\ W,AC > 0} (ACCVOL_{AC} * ACC_{W,AC,D}) <= CUBE_D$ for all $_D$

(EQ5A) $\Sigma_W (WT_W * STORES_{W,D}) +$

$\Sigma_{AC} [\Sigma_{W \text{ st } REQACC\ W,AC > 0} (ACCWT_{AC} * ACC_{W,AC,D}) <= STRESS_D$ for all $_D$

Required accessory constraint:

(EQ6A) $\Sigma_D ACC_{W,AC,D} >= REQACC_{w,ac} * \Sigma_D STORES_{W,D}$ for all $_{W,AC}$

Ship's stability constraints:

The method of numbering ordnance storage holds on a ship is to number the decks top to bottom, starting forward and working aft. Because of this numbering convention, Deck 5 on the AOE 6 class is the 1st platform in the second hold while on an AOE-1 class, deck

5 is the bottom deck in the first hold. It follows that the constraints for modeling ship stability will change with every ship class and can not be modeled generically. In this model the weights of accessories will not be factored into this formulation for two reasons: (1) The weight of most of the accessories is negligible in comparison to most of the weapon types. (2) The current trend is moving towards all weapons being ordered, shipped and stored as an all up round, ready for service. The only noteworthy exception to this is the propellant charges for 5 inch 54" ammunition. For this model, the propellent charges are modelled as an accessory.

(EQ7A) $\Sigma_W (WT_W * STORES_{W,1}) + \Sigma_w (WT_W * STORES_{W,2}) + \Sigma_w (WT_W * STORES_{W,3}) >=$
$\Sigma_W (WT_W * STORES_{W,4}) + \Sigma_W (WT_W * STORES_{W,5}) + \Sigma_W (WT_W * STORES_{W,6}) +$
$\Sigma_W (WT_W * STORES_{W,7})$

(EQ8A) $\Sigma_W (WT_W * STORES_{W,4}) + \Sigma_W (WT_W * STORES_{W,5}) + \Sigma_W (WT_W * STORES_{W,6}) +$
$\Sigma_W (WT_W * STORES_{W,7}) >=$
$\Sigma_W (WT_W * STORES_{W,8}) + \Sigma_W (WT_W * STORES_{W,9}) + \Sigma_W (WT_W * STORES_{W,10}) +$
$\Sigma_W (WT_W * STORES_{W,11})$

(EQ9A) $\Sigma_W (WT_W * STORES_{W,3}) + \Sigma_W (WT_W * STORES_{W,6}) + \Sigma_W (WT_W * STORES_{W,7}) +$
$\Sigma_W (WT_W * STORES_{W,10}) + \Sigma_W (WT_W * STORES_{W,11}) >=$
$\Sigma_W (WT_W * STORES_{W,1}) + \Sigma_W (WT_W * STORES_{W,2}) + \Sigma_W (WT_W * STORES_{W,4}) +$
$\Sigma_W (WT_W * STORES_{W,5}) + \Sigma_W (WT_W * STORES_{W,8}) + \Sigma_W (WT_W * STORES_{W,9})$

(EQ10A) $\Sigma_W (WT_W * STORES_{W,2}) + \Sigma_W (WT_W * STORES_{W,5}) + \Sigma_W (WT_W * STORES_{W,9}) >=$
$\Sigma_W (WT_W * STORES_{W,1}) + \Sigma_W (WT_W * STORES_{W,4}) + \Sigma_W (WT_W * STORES_{W,8})$

Weapon compatibility constraints:

(EQ11A) $YSTORES_{W,D} * M >= STORES_{W,D}$ for all $_{W,D}$

(EQ12A) $STORES_{WP,D} <= M * (1 - YSTORES_{W,D})$ for all $_{W,WP,D}$ st $WEPCMP_{W,WP}=0$

B. CARGO FUEL MODEL

1. Methodology

The basic idea of the model is that by tracking the amount of each commodity carried by a battle group through an operation, a logistics planner would have a valuable tool to help in planning shuttle ship requirements and schedules. By subtracting the daily commodity usage rate from the current reserves available in the battle group, the logistics planner can have an accurate, up to date logistics picture. For the specific case of the Supply class AOE, where the initial cargo fuel mix is variable, this model will provide the logistics planner an aid to facilite finding the optimal initial fuel loadout for the AOE-6 class station ship.

The first step in developing the model is to design a battle group. After the composition of the battle group is known, each combatant ship and the station ship in the battle group must be examined individually to determine the maximum quantity of each of the commodities that will be tracked is capable of being stored aboard the ship. The summation of all the individual battle group combatants, combined with the station ship cargo commodities gives the maximum amount of each commodity available for the battle group. With the AOE-6 assigned as a station ship, the JP-5 and DFM commodities have a maximum initial range.

The next step is to again return to each individual ship in the battle group and find the individual ship consumption rates during the various phases of the operation for each commodity. Again, the summation of the individual ship usage rates for each of the commodities during each phase of the operation provides the daily battle group usage rate. For this model, the previous steps were completed in Chapter III.

In the final formulation, the commodities to be tracked and the length of the operation, in days, provide the information for developing the sets. The rest of the information is used to make up the input data.

The interesting aspect of this model is that while the overall MOE is to minimize the number of CONSOLs required during the operation, the objective function in the optimization formulation is to maximize the quantity of commodities that are transferred to the CVBG. The objective function performs the task of ensuring that for every CONSOL operation, the CVBG will attempt to replenish to its initial values. To find the correct or minimum, number of CONSOLs to perform, a constraint equation will be employed with the number of CONSOL operations during the model run equal to a positive integer. This will require the user to set in a specific number that will be equal to the number of CONSOL operations throughout the operation. The user will then modify the number of CONSOL operations, over several model run iterations until the smallest number of CONSOL operations that provide a feasible solution can be found. For this model a feasible solution is a solution which maintains the battle group above the pre-determined reserve level for each commodity in the battle group throughout the 80 day operation.

The first approach to this model attempted to have an objective function that minimized the number of CONSOLs during the operation. The problem with this approach is that the initial load of cargo fuel for the AOE is a variable, so it is not possible to force the model to fully load every commodity to its initial levels at every CONSOL without using non-linear programming techniques.

2. Model Assumptions

Several assumptions were made to simplify the model. The most important assumption is that all commodities used by the battle group are aggregated and expended through the AOE, rather then by the individual units. This is done by expanding the capacity of the AOE to include the entire battle group. The advantage of this is the effect of eliminating the need to model specific underway replenishments to the combatants in the battle group. It also allows the user to set a minimum commodity level for the battle group as a whole, vice a minimum for each individual ship.

Other assumptions include:

1. One AOE is assigned to the battle group as a station ship. Sufficient shuttle ships are available to fully resupply each commodity to the initial (maximum) level at any time before one commodity drops to its minimum level. Factors such as turnaround time and distance from the ALSS will not be considered in this model.

2. Internal distribution from the AOE to the battle group occurs, but is transparent.

3. While 30% of the AOE-6 cargo fuel tanks are convertible, no other storage spaces may be used to store any other cargo than specifically assigned (for example, no placing ordnance in dry goods storage holds). The common fleet practice of deck loading dry stores and inert ordnance will also not be modelled.

4. The battle group will begin each scenario at the maximum level for all commodities.

3. Description

Indices

This model involves only two indices. The first indice is I, which represents the set of the four commodities, DFM, JP5, STORES and AMMO, that will be tracked in the model. The second indice T, represents the day of the operation, in this case day 1 through day 80.

Input Data

$MINLEVEL_I$ = This is the minimum battle group reserve level for each commodity. This reserve level is normally set by the fleet or battle group commander. It is usually measured as a percentage of the maximum commodity storage level.

$MAXLEVEL_I$ = This represents the maximum storage capacity in the battle group for each commodity. This is based upon the storage constraints of the ships in the battle group.

$USED_{I,T}$ = A table that represents the daily usage rates for each commodity for each day of the peration. Because of the large size of this table, it is entered as a separate file. The daily usage rates are dependent on which phase of the operation and the composition of the CVBG.

N = A scalar number that tells the model the exact number of CONSOL operations to perform during the operation. This number will start high and on each run be made smaller until the model can no longer find a feasible solution. This has the effect of finding the minimum number of CONSOLs based upon the CVBG composition and required minimum reserve levels.

Variables

$AOE6_{I,T}$ = This variable represents the reserve quantity of each commodity, I, available to the battle group at the completion of each day, T.

$CONSOL_{I,T}$ = Tracks the quantity of each commodity that was CONSOLed to the CVBG on each day.

$INITAOE_{I}$ = This is the variable that will tell the optimal mix of cargo fuel to carry. This is accomplished by setting a high and low range for the maximum CVBG fuel capacity which reflects the alignment of the AOE having all of its convertible tanks to DFM of all to JP5. The STORES and AMMO commodities are fixed at the maximum capacity for the ship.

DAY_{T} = A binary decision variable of whether or not to CONSOL on day T. If a 1, then the CVBG will conduct a CONSOL operation.

OBJECT = While minimizing the number of CONSOL operations, maximize the quantity of each commodity CONSOLed to the CVBG.

Equations

(EQ1B) $OBJECT = \Sigma_{I}\ [\Sigma_{T}\ CONSOL_{I,T}\ ]$

The goal of the objective function is to maximize the quantity of each commodity transferred to the battle group. This forces the model to efficiently plan each of the limited number of CONSOLs to ensure maximum efficiency.

(EQ2B) $\Sigma_{T}\ DAY_{T} = N$

This equation is where the number of CONSOL evolutions permitted during the entire operation is controlled.

(EQ3B) $AOE6_{I,T} = INITAOE_{I} - USED_{I,T} + CONSOL_{I,T}$ for all $_{I,T=1}$

This equation shows the reserve level of each commodity at the end of day 1. This equation is necessary because the initial loadout of the AOE is a variable. While it is highly unlikely that the CVBG would need to CONSOL on its first day out of port, the computer model attempts to do so if the $CONSOL_{I,T}$ were not added to this equation.

(EQ4B) $AOE6_{I,T} = AOE6_{I,T-1} - USED_{I,T} + CONSOL_{I,T}$ for all $_{I,T>1}$

This equation is the flow balance equation for each of the commodities from day 2 to the end of the operation.

(EQ5B) $AOE6_{I,T} >= MINLEVEL_I$ for all $_I$

This equation sets the minimum reserve level for each commodity in the CVBG. When any one of the four commodities reaches its minimum level a CONSOL must take place to resupply the battle group.

(EQ6B) $AOE6_{I,T} <= INITAOE_I$ for all $_I$

This equation states that once the initial AOE loadout has been determined, those capacities now become the upper bounds and the battle group may never carry more then that quantity of each commodity. This, in concert with equation 7B, also sets the upper limit on how much of each commodity may be CONSOLed.

(EQ7B) $CONSOL_{I,T} <= MAXLEVEL_I * DAY_T$ for all $_{I,T}$

This equation is where the YES or NO decision to CONSOL on day T occurs. If the decision is NO, then $CONSOL_{I,T} = 0$, if the decision is YES, then equation 1B attempts to CONSOL as much as possible, while this equation and equation 6B provide the upper bound constraint.

(EQ8B) $\Sigma_I \; INITAOE_I = 13,156,901 * .95$ for $_{I= JP5, DFM}$

This equation tells the model that the sum of the initial JP-5 and DFM fuel load, in gallons, is equal to the maximum fuel capacity for the battle group. INITAOE is given an upper and a lower bound for the commodities DFM and JP-5 in the model. This range is based on the convertible tank storage capacity aboard the AOE-6 class. The quantity, .95, is the stow factor for the fuel tanks in the battle group.

(EQ9B) $INITAOE_I = 1,658.42$ for $_{I= STORES}$

(EQ10B) $INITAOE_I = 5,016$ for $_{I= AMMO}$

Based upon the unclassified ordnance and stores capacities for each ship in the battle group, equation 9B and 10B tell the model to have a maximum initial loadout of these two commodities. The final three equations are utilized only if modeling a ship that has a variable initial maximum load such as the AOE-6 class. A stowage factor was not applied to the final two equations. The reason for this is that the ship weapon loads were taken from a notional load list. The weapons, like the stores, are already aboard the ship, so a stow factor is not required. For the cargo stores and ordnance, the ship design contractor's expected loadout, by weight (tons), was used as a planning factor. Stow factors affect volume, not weight, so again this factor was dropped. If the station ship in the scenario was an AOE-1 class, the INITAOE variable would not be required, and the initial loadout would be equal to the maximum loadout.

4. Formulation

Indices

I	=	Commodity type.
T	=	Day of the operation.

Input Data

$MINLEVEL_I$	=	Min CVBG reserve (on-hand) level of commodity I.
$MAXLEVEL_I$	=	Max CVBG level of commodity I.
$USED_{I,T}$	=	Quantity of commodity I consumed on day T.
N	=	A scalar equal to the number of CONSOL operations.

Variables

$AOE6_{I,T}$	=	CVBG reserve level of commodity I on day T.
$CONSOL_{I,T}$	=	Amount of commodity I consoled on day T.
$INITAOE_I$	=	Initial (and maximum) quantity of commodity I.
DAY_T	=	Yes or no decision to CONSOL on day T.
OBJECT	=	Minimize number of CONSOLs and refill to capacity.

Equations

The formulation is then:

Maximize:

(EQ1B) $OBJECT = \Sigma_I \; [\Sigma_T \; CONSOL_{I,T}]$

Subject to:

Find the minimum number of CONSOLs:

(EQ2B) $\Sigma_T \ DAY_T = N$

The flow balance equations:

(EQ3B) $AOE6_{I,T} = INITAOE_I - USED_{I,T} + CONSOL_{I,T}$ for all $_{I,T=1}$

(EQ4B) $AOE6_{I,T} = AOE6_{I,T-1} - USED_{I,T} + CONSOL_{I,T}$ for all $_{I,T>1}$

Observe minimum reserve levels:

(EQ5B) $AOE6_{I,T} >= MINLEVEL_I$ for all $_I$

Observe storage capacities:

(EQ6B) $AOE6_{I,T} <= INITAOE_I$ for all $_I$

Did a CONSOL occur on a given day:

(EQ7B) $CONSOL_{I,T} <= MAXLEVEL_I * DAY_T$ for all $_{I,T}$

The initial fuel load on the AOE:

(EQ8B) $\Sigma_I \ INITAOE_I = 13{,}156{,}901 * .95$ for $_{I= JP5,DFM}$

The initial stores and ordnance load:

(EQ9B) $INITAOE_I = 1{,}658.42$ for $_{I= STORES}$

(EQ10B) $INITAOE_I = 5{,}016$ for $_{I= AMMO}$

C. GENERAL ALGEBRAIC MODEL SYSTEM

The General Algebraic Modeling System, or GAMS, is used to solve both models. "GAMS is designed to make the construction and solution of large and complex mathematical programming models more straightforward for programmers and more comprehensible to users of models from other disciplines" [Ref. 10: Preface]. In the first model, GAMS is used to find the maximum benefit of the entire ordnance load aboard the AOE. In the second model, GAMS will be used to find the optimal initial DFM to JP-5 cargo fuel mix to carry on the AOE.

Mixed integer programs, like these two models, are generally difficult to solve and often require extensive computing resources. GAMS provides an option for relative and absolute termination tolerances (OPTCR and OPTCA) which can be defined by the user, allowing GAMS to stop when the objective function value is within a certain tolerance of the optimal solution. Both models will use termination boundaries of five percent to aid in determining a final solution.

VI. SUMMARY OF RESULTS AND CONCLUSIONS

A. ORDNANCE LOAD MODEL RESULTS

This GAMS program models the loading of ordnance aboard a Supply class AOE. The measure of effectiveness for this model is the overall benefit of the ordnance loadout to a carrier battle group. For the AOE-6 loadout, the objective function value was 109,972.8734. Unfortunately, this program has only been developed and executed for one class of ship, so the objective function value has no other results with which to compare and develop conclusions. One alternative scale of measurement is to look at the total number of each weapon type loaded aboard the AOE-6. Of the 21 weapon types used in the model, the program loaded 13 weapon types to the maximum allowable level, six at the minimum level and two at levels between the minimum and maximum. Table 17 shows the number of each weapon loaded aboard the AOE-6. Appendix I contains the complete output file showing which deck to store each of the weapons as well as the necessary accessories.

Table 17 Final AOE-6 Weapons Load

Weapon Type	**Value**	**Min**	**Max**	**Number Loaded**	**Category**
Sidewinder	47.9	10	90	90	Maximum
Sparrow III	51.2	10	20	20	Maximum
Phoenix	34.4	10	20	10	Minimum
SM-2 (rail launch)	43.6	10	20	10	Minimum
Chaff	64.1	10	150	150	Maximum
Sonobouys	60.7	10	150	150	Maximum
Walleye	58.1	10	150	10	Minimum
Harm	62.9	10	200	125.53	**Neither**
Rockeye	53.3	10	150	150	Maximum
Maverick	58.0	10	150	150	Maximum
Hellfire	42.4	10	75	75	Maximum
Harpoon (air)	44.3	10	15	10	Minimum
CIWS ammo	58.1	10	80	80	Maximum
Sea Sparrow	49.1	10	25	25	Maximum
MK60 mine	24.6	10	25	10	Minimum
MK46 torpedo	43.0	10	15	15	Maximum
ASROC (rail)	27.5	10	15	10	Minimum
2000 lb bomb	59.5	10	250	143.81	**Neither**
1000 lb bomb	64.5	10	250	250	Maximum
500 lb bomb	61.4	10	250	250	Maximum
5'54" ammo	61.8	10	150	150	Maximum

For this model to run successfully, the variable that represents the number of weapons to load on each deck can not be an integer variable. During runs where the number of unit rounds of each weapon was treated as an integer, the problem proved to be too complex, required too many iterations and an optimal solution was never found. By treating the weapon as a positive continous variable, vice an integer variable, the complexity of the problem is reduced, the required number of iterations is reduced and an optimal solution can be found. The drawback to this method is the answer will include fractions of weapons such as those shown in

Table 19 for the two "Neither" category weapons. A review of the output file shown in Appendix I will also reveal this drawback for some of the weapons and accessories that are stored on several decks, with fractions of weapon loads on each deck. In these cases, the experience of the load planner and ship's company will dictate which course of action to take. In the case of the AOE-6, the limiting factor is the lack of available weapons storage area. For this case, the fraction portion of the weapon will probably be rounded down to the next lower whole unit load.

Another yardstick of the worth of the ordnance onload is the total tonnage of ordnance the GAMS program was able to place aboard the AOE. For the data parameters as shown in Appendix I, the total ordnance tonnage was 2,354. The ship design specifications anticipate the required ordnance load for this class of ship to be 1,800 tons. This large discrepancy is a result of the limited selection of weapon types loaded aboard the AOE for this model. The weapons loaded in this program were all larger, heavier types of ordnance. When the loadout includes lighter, smaller or less efficiently stored ordnance such as blasting caps, detonation chord or small arms ammunition, the result will be a lower overall tonnage of the ordnance loadout.

The issue of compatibility also did not play a major role in the program results. While the Harpoon missile did test the model's compatibility constraints, should the loadout include other ordnance types that require special handling, such as star shells (pyrotechnics), possibly special weapons or phosphorous 5 inch 54" rounds, the compatibility constraint would play a much larger role in the final load list and would also probably lower the total loadout tonnage.

The important structural design feature of the AOE-6 class, brought to light by the results, is that even though the total ordnance tonnage was greater than the contractors anticipated tonnage, the loadout did not come within 60% of the rated stress load for any of the storage decks. This significant detail allows for the free use of forktrucks in the ammunition holds to move ordnance, without the fear of over stressing the deck.

B. CARGO FUEL MODEL RESULTS

When reviewing the results of the Battle Group Commodity Level Program, it is very important for the reader to understand that the results are relative to the data used in the program. While every effort has been made to model the commodity usage for a battle group involved in a real world contingency, several items must be mentioned to ensure the reader fully understands the limitations of this thesis program.

The figures used to arrive at the maximum fuel capacities of DFM and JP-5 for the battle group are all taken from unclassified sources.

The ordnance expenditure rate can fluctuate up or down depending upon the type of weapons being employed. If the mission requires a larger number of advanced, smart weapons, the ordnance usage may drop. Ordnance usage is also dependent on the threat to the battle group from air, surface and submarine contacts. No surface ships fired anti-air or anti-surface missiles, or torpedoes during the Persian Gulf War. Should a scenario develop against a foe with a formidable AAW, ASUW or ASW threat, the usage rates may be higher.

The JP-5 daily usage rate is dependent on the number of sorties flown. A fleet logistics planner would have to evaluate the strike mission requirements as well as the defensive posture of the battle group to arrive at his final JP-5 usage rates.

For this program, the minimum reserve level of any commodity will be set at 70%. The minimum level of the cargo fuel is based on the minimum possible JP-5 or DFM loadout (to find the 70% DFM level, assume all convertible tanks are carrying JP-5, total the remaining DFM in the battle group and multiply by .7). Sensitivity analysis discussed later in this chapter will look at the impact of lowering this level, but fleet experience indicates a preference to have a minimum on-hand availability of at least 70%. The first run for each scenario will look at finding the optimal fuel mix and the minimum number of CONSOLs. Two more model runs will be completed by loading the convertible tanks aboard the AOE-6 with all JP-5 and then all DFM. The goal is that at the end of all four scenarios, a cargo fuel mix will be found that when placed in all four scenarios will come as close as possible to replicating the minimum number of CONSOLs for each of the individual scenarios as the generated optimal fuel mix. This will find the best cargo tank configuration for an AOE-6 to respond to all taskings without having to empty and convert fuel tanks.

The results of the model runs were slightly different than anticipated. What the model would do, instead of totally reloading the battle group to 100% at each CONSOL for each commodity, is resupply each commodity at such a level as to just make it through to the next CONSOL, until the last CONSOL of the operation where it would proceed to load to 100% for every commodity. By conducting CONSOLs in this manner, it still managed to maximize the objective function, still managed to minimize the number of CONSOLs, it just did not act in a way that a fleet logistics planner would. While it did not do this more then 35% of the time, it required a more detailed analysis of the results to discover which commodity was the limiting factor. The difference between the model and the human planner is the model is strictly looking to optimize the allocation of CONSOLs to gain a maximum benefit, while the human planner would be taking other factors such as operations, availability of shuttle ships and the threat level into account when planning CONSOLs. The main focus is looking at which commodities were the limiting factors for the battle group and what is the recommended split of cargo fuel for the AOE-6 class station ship to carry.

1. Nuclear Powered CV and Escorts (Scenario 1)

The model required a total of seven CONSOLs for the 80 day operation. Two CONSOLs occurred during the transit phase, both motivated by the DFM level, two CONSOLs occurred during the presence, both due to JP-5 reaching the minimum level, and the final three, also motivated by low JP-5 levels, occurred during the combat phase. The model needed 9 CONSOLs with a 40% JP-5/60% DFM cargo fuel mix and 12 CONSOLs for a 70% JP-5/30% DFM split.

The model recommends a split of JP-5 to DFM cargo fuel of 55% JP-5/45% DFM split. Looking at the convertible tank capacities, shown in Table 2 and Appendix D, the logistics decision maker could use the following tank configuration for the AOE-6:

1. Have either tank 7-265 or 330-0-FF/JJ and 7-150-0-FF/JJ carry DFM while the rest of the convertible tanks carry JP-5. This would provide for a 54.7% JP-5/45.3% DFM split.

The detailed program and results for this particular model run are available in Appendices K and L.

2. Conventional Powered CV and Escorts (Scenario 1A)

The model required a total of 9 CONSOLs to complete the operation. One CONSOL was required due to low DFM levels during the transit phase. Three CONSOLs were required during the presence phase, two due to low DFM levels and the third due to a combination of low DFM and JP-5 levels. The final five CONSOLs occurred during the combat phase, two as a result of low DFM levels and three as a result of low JP-5 levels. The model needed 11 CONSOLs with a 40% JP-5/60% DFM cargo fuel mix and 13 CONSOLs for a 70% JP-5/30% DFM split.

The model recommends a 48% JP-5/52% DFM split. For this mix the logistics planner would have one option:

1. Select tanks 7-330-1 and 2-FF/JJ to carry JP-5 and fill the remaining convertible tanks with DFM. This would provide a 48.4% JP-5/51.6% DFM split.

3. Nuclear Powered CV, Escorts and 3 Ship ARG (Scenario 1B)

The model required a total of 8 CONSOLs to complete the operation. One CONSOL occurred during the transit phase due to low DFM levels. Two CONSOLs occurred during the presence phase, again due to low DFM levels. The remaining five CONSOLs occurred during the combat phase, three due to low JP-5 levels and two motivated by the combination of low DFM and low JP-5 levels. The model needed 12 CONSOLs with a 40% JP-5/60% DFM cargo fuel mix and 11 CONSOLs for a 70% JP-5/30% DFM split.

The model recommended a 60% JP-5/40% DFM cargo fuel split. This can be accomplished by:

1. Aligning tank 7-150-0-FF/JJ to carry DFM and the remaining convertible tanks to carry JP-5. This configuration would produce a 61% JP-5/39% DFM cargo fuel split.

2. Aligning tanks 7-265 and 330-0-FF/JJ to carry DFM and the remaining convertible tanks to carry JP-5. This configuration would produce a 59% JP-5/41% DFM cargo fuel split.

4. Conventional Powered CV, Escorts and 3 Ship ARG (Scenario 1C)

The model required 9 CONSOLs to complete the operation. One CONSOL was required during the transit phase due to low DFM levels. Two CONSOLs were required during the presence phase, motivated by both low DFM and JP-5 levels. The remaining six CONSOLs occurred during the combat phase, all motivated by low JP-5 reserve levels. The model needed 17 CONSOLs with a 40% JP-5/60% DFM cargo fuel mix and 11 CONSOLs for a 70% JP-5/30% DFM split.

The model recommended a 55% JP-5/45% DFM cargo fuel split. The cargo fuel tank configuration would be the same as that of Scenario 1 described previously.

C. ANALYSIS

While it is apparent from the results of the Cargo Fuel model that fuel was the limiting factor in every scenario, analysis of both models is required to develop insights into both the rearming and refueling missions of the AOE-6 class. Had a more ordnance intensive scenario been utilized, fuel may not have been the limiting factor in every case.

1. Ordnance Load Model

The most significant analysis from the load list program is that the ammunition cargo hold volume is the limiting factor in the amount of ordnance an AOE-6 class ship can carry. The results of the model conclude that if the ordnance carrying capacity of the AOE-6 is to improve, additional improvements in the amount of storage capacity available must be made or a more efficient storage method, a higher stow factor, must be developed. Based on the analysis of the model, the only recommended method of improving the ordnance storage features of the AOE-6 is to "jumboize" the ship class. Restoring the ammunition hold that was deleted in the design phase would provide the AOE-6 25% more ammunition storage volume, which is the constraining factor, as well as increasing the overall stores and cargo fuel capacities.

2. Cargo Fuel Model

The model runs of the four scenarios provide some interesting results. In all of the model runs, fuel, either JP-5 or DFM, was the limiting factor that required the battle group to CONSOL. The optimal fuel mix for each scenario is provided in the model results. Of great interest to the logistics planners would be at what tank configuration would the AOE-6 be most effective to cover a broad spectrum of deployment options. Table 18 provides a review of the data collected from the scenario results in which the number of CONSOLs is compared for the optimal and the extreme fuel mixes.

Table 18 Review of Battle Group Fuel Figures

Scenario	**Optimal Fuel Mix**	**# CONSOLs at optimal mix**	**# CONSOLs at 40% JP-5/60% DFM**	**# CONSOLs at 70% JP-5/30% DFM**
CVNBG 1	55% JP-5/ 45% DFM	7	9	12
CVBG 1A	48% JP-5/ 52% DFM	8	11	13
CVN/ARG 1B	60% JP-5/ 40% DFM	8	12	11
CV/ARG 1C	55% JP-5/ 45% DFM	9	17	11

Based upon the data in Table 18, the AOE-6 cargo fuel tanks were aligned to carry 54.7% JP-5 and 45.3% DFM by having convertible tanks 7-150 and 265-0-FF/JJ carry DFM and the rest of the convertible tanks carry JP-5. This fuel mix was entered into the model for all four scenarios. The model was then executed for all four scenarios, each with the same cargo fuel configuration aboard the AOE-6. Table 19 shows the comparison for the number of required CONSOLs based on the optimal and this selected fuel percentage mix.

Table 19 Comparison of Optimal and Selected Fuel Mix

Scenario	**Optimal Fuel Mix**	**# CONSOLs at optimal mix**	**# CONSOLs at 54.7% JP-5/45.3% DFM**	**Difference**
CVNBG 1	55% JP-5/ 45% DFM	7	7	**0**
CVBG 1A	48% JP-5/ 52% DFM	8	8	**0**
CVN/ARG 1B	60% JP-5/ 40% DFM	8	8	**0**
CV/ARG 1C	55% JP-5/ 45% DFM	9	9	**0**

As shown in Table 19, aligning the AOE-6 to carry a 54.7% JP-5/45.3% DFM cargo fuel mix will have no impact on the required number of CONSOL operations. Based upon the battle group configurations described in Chapter III, the AOE-6 station ship will be equally effective in all scenarios with one cargo fuel alignment.

D. SENSITIVITY ANALYSIS

1. Ordnance Load Model

From the results produced in the ordnance loading model, it is clear that two parameters affect the final generated load list; the benefit and the volume of each weapon. Attempts to influence the final results by modifying the weight of the weapons or the stability constraints yielded no changes. The benefit of each weapon was taken from the Chapter IV survey results and is employed in the objective function. The benefit of each weapon was derived from a comparison with other weapons in a group. To arbitrarily change any one weapon's worth as compared to the other weapons in the group is not realistic, so only the volume of the unit round of each weapon will be explored.

For this analysis, two additional ordnance loads will be completed. The first will look at a 10% volume increase for each of the 21 weapon types. The rationale for this is that as the military moves more towards issuing weapons with all the required accessories, or as an All-Up-Round (AUR), the size of the unit load will increase. The second will look at a 10% decrease in the size of the 21 weapon types. The thought here is that as technology can produce better fuels, more powerful warheads and better guidance systems, the size of weapons may actually decrease. Again, the purpose is to see the effect of these volume changes on the final ordnance loadout. Table 20 shows the results of this sensitivity analysis.

Table 20 Results of Optimal Load List Sensitivity Analysis

Weapon Type	Benefit	Number Loaded	Number Loaded (10% increase)	Number Loaded (10% decrease)
Sidewinder	47.9	90	90	90
Sparrow III	51.2	20	20	20
Phoenix	34.4	10	20	20
SM-2 (rail launch)	43.6	10	10	10
Chaff	64.1	150	150	150
Sonobouys	60.7	150	150	150
Walleye	58.1	10	10	34.80
Harm	62.9	125.53	189.49	149.36
Rockeye	53.3	150	150	133.88
Maverick	58	150	150	150
Hellfire	42.4	75	75	75
Harpoon (air)	44.3	10	15	10
CIWS ammo	58.1	80	80	80
Sea Sparrow	49.1	25	25	25
MK60 mine	24.6	10	10	10
MK46 torpedo	43	15	15	15
ASROC (rail)	27.5	10	15	15
2000 lb bomb	59.5	143.81	**10**	200
1000 lb bomb	64.5	250	183.35	200
500 lb bomb	61.4	250	250	250
5'54" ammo	61.8	150	150	150
Total Tonnage		2354	2045	2470

With an increase in volume of 10%, the total ordnance tonnage dropped by 309 tons, or 13% of the original ordnance load. The primary weapons lost during the volume increase occurred were 2,000 and 1,000 lb bombs. While the load did include more Harpoon (5), ASROC (5), HARM and Phoenix (10), it did so at a cost of over 400 bombs (266 2,000 lb bombs (133 pallets, 2 bombs each) and 198 1,000 lb bombs (66 pallets, 3 bombs each)).

The decrease in volume of 10% added only an additional 116 tons, or 5% to the original load. The weapons that decreased in the final load were 1,000 lb bombs (50 pallets or 150 total bombs) and Rockeye (16), but the final load included 56 more pallets of 2,000 lb bombs(112 bombs), more ASROC (5), HARM (24), and Walleye (24).

Again, this model loads ordnance as dimensionless objects. This allows the model to perfectly fit each container and pallet with no gaps. When loading actual squares, rectangles and boxes, the fit may not be as tight, hence the need for dunnage and bracing. It is obvious from this model that with the advanced structural design and strength of the ammunition holds aboard the AOE-6 class, the available storage volume will continue to be the primary constraint. This sensitivity implies that the AOE-6 will be much more affected by increases in weapon volume then by decreases. The real world loading of ammunition may not be as adversely impacted by the 10% weapon volume increase as was the model, but an increase will have a much more pronounced impact on the final load list then a 10% decrease in the volume.

2. Cargo Fuel Model

a. *Impact of Lowering the Minimum Commodity Reserve Levels*

With a limited number of shuttle ships that can be deployed at any given moment, just how long can an AOE keep a CVBG fueled, armed and supplied? What if the contingency developed in a place where the Navy did not have a regular supply pipeline, yet the carrier and her escorts were required to go? To look at these questions, the reserve commodity levels were dropped from 70% to 30% in increments of 10% to see the impact on the recommended optimal fuel mix, as well as the required number of CONSOLs. Table 21 shows the results of the model runs.

Table 21 Results of Lowering Reserve Commodity Levels

Reserve Commodity Level	Scenario 1 CVNBG		Scenario 1A CVBG		Scenario 1B CVNBG/ARG		Scenario 1C CVBG/ARG	
Percentage	Fuel Mix	# of CONSOL	Fuel Mix	# of CONSOL	Fuel Mix	# of CONSOL	Fuel Mix	# of CONSOL
70	55/45	7	48/52	8	60/40	8	55/45	9
60	50/50	6	55/45	6	64/36	7	64/36	7
50	52/48	5	54/46	6	58/42	6	64/36	7
40	46/54	5	55/45	4	66/34	5	64/36	6
30	53/47	4	58/42	4	64/36	5	63/37	5

Note: Fuel Mix is %JP-5/%DFM

As shown in Table 21, the recommended optimal fuel mixes are within 10% of the selected 54.7% JP-5/45.3% DFM fuel mix with one exception (40% reserve level for Scenario 1B). It should also be noted that only in an extreme emergency would a ship willingly go as low as 40% reserve level for fuel. At 30% liquid load, the AOE-6 becomes unstable and would have to rely on sea water ballast to regain stability. While the number of CONSOLs can be reduced by up to 25% for a 20% decrease in reserve levels, the logistical and operational planners would have to weigh the risks against the benefits of possibly using shuttle ships to top off the escorts, sudden unexpected emergent taskings, longer off station time for the battle group and a host of other factors when determining minimum commodity levels.

b. *Impact of Having a Smaller Battle Group*

The battle groups developed for these four scenarios all included six escorts. As the military attempts to reduce operating costs, battle groups with as few as three escorts may be tasked to cover contingency operations. The first two scenarios will be revisited to look at the impact on the optimal fuel mix of removing assigned escorts from the battle groups. With the assumption that the smaller battle groups will cover the same contingencies as the larger, six escort battle group, the daily ordnance and JP-5 usage rates will remain the same while the DFM and stores rates will decrease with each iteration that removes another escort. The input table that contains the daily usage rate information will be modified to contain this information. The model parameter that shows the maximum DFM, ordnance and stores rate will be modified to reflect the loss of the escorts. The minimum reserve level will be 70% for each model iteration, with one escort being removed from each scenario when the minimum number of CONSOLs and the optimal fuel mix have been found. Table 22 shows the final results of the model runs from removing the escorts.

Table 22 Impact of Fewer Escorts on Optimal Fuel Mix

Escorts Removed from Scenario	**Optimal Fuel Mix & Number of CONSOLs Scenario 1 (CVNBG)**	**Optimal Fuel Mix & Number of CONSOLs Scenario 1A (CVBG)**
NONE	55% JP-5/45% DFM 7 CONSOLs	48% JP-5/52% DFM 8 CONSOLs
1 DDG-993	56% JP-5/44% DFM 7 CONSOLs	49% JP-5/51% DFM 8 CONSOLs
1 DDG-993 1 CG-47	57% JP-5/43% DFM 7 CONSOLs	51% JP-5/49% DFM 8 CONSOLs
1 DDG-993 1 CG-47 1 DDG-51	59% JP-5/41% DFM 7 CONSOLs	52% JP-5/48% DFM 8 CONSOLs

Reviewing the results presented in Table 22, two very interesting facts become apparent: (1) reducing the number of escorts had no impact on the required number of CONSOLs and (2) very little change is noted in the optimal JP-5/DFM cargo fuel split.

When reviewing the required number of CONSOLs for these two scenarios, it appears that the benefit in having a smaller number of escorts will be in the reduced need for shuttle ship capacity. One possible explanation for little change in both the fuel mix and the required CONSOLs is that as the maximum DFM capacity is reduced, along with the daily DFM usage rate, the JP-5 capacity and usage rates remain the same. The model, because of the slight shift in recommended DFM to JP-5 levels, actually compensates for the changes in the lower maximum DFM level and daily usage rates. Many would argue that the minimum number of CONSOLs should actually decrease. While this would seem true to some observers, the way the program is modelled prevents this fact from coming to light. One key element is that the operation ceases at day 80, causing an "end effect". This means that the ships in the battle group can be replenished with CONSOL 7 at day 72 and be at 71% on day 80, or the battle group can be replenished on day 79 and be at 98% on day 80. The objective function prefers the second alternative, but the model must first find a feasible solution. In real life, another CONSOL would be scheduled for day 82 as the ships departed station for the first battle group. It is a very real possibility that the scenario is not long enough to produce an appreciable difference in the required number of CONSOLs. In the case of the scenarios involving the conventional powered carrier, the primary reason for for no meaningful difference in the number of CONSOLs is that the escorts have and use such a small percentage of DFM (and stores) relative to the CV.

The most important information gained from these results, is that even with changing CVBG compositions, the recommended fuel mixes all are within 7% of the selected 44.7% JP-5/54.3% DFM cargo fuel split.

E. SUBSTITUTING THE AOE-1 CLASS FOR THE AOE-6 CLASS AS THE ASSIGNED BATTLE GROUP STATION SHIP

As the Navy moves into the 21st century, it is readily apparent that only eight station ships, four in the AOE-1 class and four in the AOE-6 class, will be available to deploy with the currently projected 12 carrier battle groups. This thesis investigates the design features of the AOE-6 class in depth, as well as analyzing the commodity storage capacities and how those capacities impact CVBG operations. While it is readily apparent that the habitability, combat survivability and the overall shipboard living environment will be much better on a newly constructed AOE-6 class ship as opposed to the aging AOE-1 class ship, will the cost saving design decisions that removed 56 feet of ship length from the AOE-6 class materialize into a problem that will possibly impact fleet operation well into the next century?

In an attempt to examine this question, both GAMS programs were edited to contain data for an AOE-1 class station ship, instead of the AOE-6.

The motivation for examining this particular problem originated at Naval Weapons Station, Earle, NJ. The lead load planner, Mr. Robert Aten, conducted a shipboard survey of the ammunition holds aboard the USS Supply, located in Norfolk, VA. After taking measurements of the ordnance holds, it became apparent that the AOE-6 did indeed have much less storage volume then the AOE-1 class. When this information became available to CINCLANTFLT, Mr. Aten was directed via the chain of command to take the USS Seattle (AOE 3) tailored load list [Ref. 23] and load that aboard the AOE-6 [Ref. 15]. As Mr. Aten had anticipated, the Seattle's tailored load list was not able to be loaded aboard Supply, forcing Mr. Aten to ask his superiors for guidance on which ordnance types to drop from the list. The second motivation was provided by Mr. Marvin Miller of the Underway Replenishment Department, Port Hueneme Division of the Naval Surface Warfare Center. During a phone interview with Mr. Miller, he expressed concern over the loss of one UNREP station and the deletion of the fourth ammunition hold [Ref. 19]. His primary concern was that the Navy had spent a great deal of time, money and effort to bring the AOE-6 class into the fleet and that the Navy may have actually purchased less commodity capacity than a class of ships already in the fleet. When Mr. Miller was informed of the topic and scope of this thesis, he stated that it might be useful to run the same battle group commodity program and see just how much of a difference exists between the AOE-1 and the AOE-6 classes.

1. Ordnance Load Model

To convert the optimal load list program from loading an AOE 6 class ship to loading an AOE 1 class (parameters for USS Seattle (AOE 3) were used for this thesis) the following parameters in the model were modified from those shown in Appendix I:

Indices - the number of storage decks aboard ship increased from 11 to 20.

Input Data - $CUBE_D$ and $STRESS_D$ were changed to match the volume and deck stress of AOE 3 [Refs. 16 and 21].

Equations - The equations representing the stability constraints were edited to be applicable to the AOE 3.

The first model runs with this data provided some interesting results. What the model would do to circumvent the stability constraint, was to load a very large number of weapon accessories into the necessary holds. While these accessories added no value to the objective function, they did increase the total tonnage of the ordnance loadout with relatively useless items such as 1500 MK46 igniter kits. A second modification was made to the required accessory constraint to ensure that the model only loaded the same number of accessories as weapons. This was not necessary for the AOE-6 model run as volume was the only constraint for that model. These changes and the results of the model run for these changes are available in Appendix J.

The first, direct method of comparison is the overall objective function value. For the AOE 3 model run, the objective function value was 128,693.3473 as compared to 109,972.8734 for the AOE 6 model. Again, with only two model runs, it is very hard to determine any magnitude to the difference of the two objective functions. The only conclusion supportable from this information is that the AOE-3 ordnance load is some magnitude better then the AOE-6 ordnance load. The second method of comparison is total tonnage. The total ordnance tonnage for the AOE-3 model is 2,905.28 tons as compared to the AOE-6 tonnage of 2,354.31. Table 23 shows a direct comparison of the number of each weapon loaded aboard AOE-3 and AOE-6.

Table 23 Comparison of AOE-3 vs AOE-6 Weapons Load

Weapon Type	Value	Min	Max	Number Loaded Aboard AOE-6	Number Loaded Aboard AOE-3	Diff +/-
Sidewinder	47.9	10	90	90	83.85	-6.15
Sparrow III	51.2	10	20	20	20	0
Phoenix	34.4	10	20	10	10	0
SM-2 (rail)	43.6	10	20	10	20	+10
Chaff	64.1	10	150	150	150	0
Sonobouys	60.7	10	150	150	150	0
Walleye	58.1	10	150	10	150	+140
Harm	62.9	10	200	125.53	200	+74.47
Rockeye	53.3	10	150	150	150	0
Maverick	58	10	150	150	150	0
Hellfire	42.4	10	75	75	75	0
Harpoon (air)	44.3	10	15	10	15	+5
CIWS ammo	58.1	10	80	80	80	0
Sea Sparrow	49.1	10	25	25	25	0
MK60 mine	24.6	10	25	10	10	0
MK46 torpedo	43	10	15	15	15	0
ASROC (rail)	27.5	10	15	10	15	+5
2000 lb bomb	59.5	10	250	143.81	236.49	+92.7
1000 lb bomb	64.5	10	250	250	250	0
500 lb bomb	61.4	10	250	250	250	0
5'54" ammo	61.8	10	150	150	148.18	-1.82

It is readily apparent that the AOE-3 does carry a significantly greater number and tonnage of weapons then the AOE-6. Where volume was the only constraining factor for the AOE-6 model, the AOE-3 model was a combination of all factors. Analysis indicates that the stability constraint prevents the ship from being loaded to an even greater level. It should also be noted that one entire storage deck was empty for this model.

Earlier statements in this thesis correctly indicated that the stability constraints are not essential when loading ammunition aboard an AOE. When loading 3,000 tons of ordnance aboard an AE, it is vitally important for ship's stability that the weight be distributed properly. The addition of 3,000 tons of ordnance on an AOE does not impose the same constraints. With an AOE, the weight of seven million gallons of cargo fuel, stored forward and low in the ship, as well as over one million gallons of bunker fuel, can compensate for the placement of the ordnance in maintainig the ship's stability. Another model run was completed for both the AOE-6 and the AOE-3 models with the stability constraints removed. As expected, there was no change for the AOE-6, as that model run was constrained by the available storage volume of the ship. The AOE-3 class showed a drastic change. Table 24 shows a comparison of the AOE-6, the AOE-3 with stability constraints and then the AOE-3 without stability constraints.

Table 24 Comparison of AOE-3 vs AOE-6 Results

Measurement	Load Aboard AOE-6	Load Aboard AOE-3 (with stability)	Load Aboard AOE-3 (w/o stability)
Objective Function Value	109,972.8734	128,693.3473	130,522.8080
Total Tonnage	**2,354.31**	**2,905.28**	**2,975.65**

Weapon Type	Min	Max	Number Loaded Aboard AOE-6	Number Loaded Aboard AOE-3 (with stability)	Number Loaded Aboard AOE-3 (w/o stability)
Sidewinder	10	90	90	83.85	90
Sparrow III	10	20	20	20	20
Phoenix	10	20	10	10	20
SM-2 (rail)	10	20	10	20	20
Chaff	10	150	150	150	150
Sonobouys	10	150	150	150	148.44
Walleye	10	150	10	150	150
Harm	10	200	125.53	200	200
Rockeye	10	150	150	150	150
Maverick	10	150	150	150	150
Hellfire	10	75	75	75	75
Harpoon (air)	10	15	10	15	15
CIWS ammo	10	80	80	80	80
Sea Sparrow	10	25	25	25	25
MK60 mine	10	25	10	10	25
MK46 torpedo	10	15	15	15	15
ASROC (rail)	10	15	10	15	15
2000 lb bomb	10	250	143.81	236.49	250
1000 lb bomb	10	250	250	250	250
500 lb bomb	10	250	250	250	250
5'54" ammo	10	150	150	148.18	150

Once the stability constraints have been removed, the AOE-3 loadout filled every weapon to the maximum level possible except for 1.56 unit rounds of sonobouys. The key fact here is that of the 20 storage decks, nine were volume constrained, four were weight constrained and one deck was compatibility constrained. One deck was completely empty! It is clear that with some structural reinforcement to the decks that are weight constrained, 11 storage decks for the AOE-3 class still have room to load more ordnance aboard the ship. Even with the stability constraints, a larger, more diverse load list will still permit the AOE-3 to carry up to 30% more of an ordnance loadout then the AOE-6.

2. Cargo Fuel Model

When comparing the performance of the AOE-6 class to the AOE-1 class, the only area that can be measured is the difference in the required number of CONSOLs for the two station ships. During the comparison of the AOE-6 and the AOE-3 in the previous section, it is readily apparent that the Seattle (AOE 3) can carry more ordnance then the Supply (AOE 6). Ordnance however, was never a limiting factor in any scenario. The AOE-1 class also carries more dry and refrigerated stores then the AOE-6. However, fuel, DFM and JP-5, was the limiting factor. The question that needs to be answered is: Does the convertible tank design of the AOE-6 class give that ship enough flexibility to compensate for more storage capacity aboard the AOE-1 class?

To convert the GAMS model from the AOE-6 to the AOE-1 station ship, the variable INITAOE was deleted, and the parameter MAXLEVEL was changed to match the battle group commodity totals with the AOE-1 as the station ship. Table 25 shows the comparison in the minimum required number of CONSOLs for each Scenario with an AOE-6 and then with an AOE-1 class station ship. The AOE-6 and AOE-1 have the same unclassified ship's ordnance loadout, the same ship's cargo loadout, and the same ship's bunker fuel loadout. As for cargo fuel, the AOE-1 has roughly a 7.2 million gallon capacity (stow factor included), with a fixed 40% JP-5, or 2,669,177 gallons JP-5, and 60% DFM, or 4,460,344 gallons DFM. The AOE-1 contains an extra 15 thousand cubic feet, or 113.4 tons of stores capacity over the AOE-6 as well as a 30 thousand cubic feet, or a design load of 400 tons, of extra capacity for weapons over the AOE-6. The daily usage rates remain the same for ordnance, JP-5 and stores, with a slight decrease in the daily usage rate of DFM.

The results for the AOE-6 are the minimum number of required CONSOLs at the optimal fuel mix at 70% reserve levels. The AOE-1 class model will be completed with a 70% reserve commodity level also.

Table 25 Comparison of AOE-1 vs AOE-6 Station Ship

Scenario	**Required Number of CONSOLs with AOE-6**	**Required Number of CONSOLs with AOE-1**	**Difference (+/-)**
Scenario 1 CVNBG	7	8	+1
Scenario 1A CVBG	8	10	+2
Scenario 1B CVNBG/ARG	8	10	+2
Scenario 1C CVBG/ARG	9	12	+3

In every scenario, the required number of CONSOLs was higher with an AOE-1 class station ship then with an AOE-6! The limiting commodity in every scenario was JP-5. The AOE-1 class station ship provides only a fixed quantity of JP-5, which during the combat phase requires the battle group to CONSOL at fixed intervals, increasing the total minimum required number. The advantage of the AOE-6 design over the AOE-1 design is the fuel mix can be optimized to account for the different demand levels of JP-5 during combat and DFM during transit, thus minimizing the number of CONSOLs. The lack of total JP-5 capacity is more apparent in the battle groups centered around a conventional powered carrier. While a CVNBG carries one miilion more gallons of JP-5 then a CVBG, the quantity of JP-5 consumed in the scenarios remains constant.

From these model runs, it would appear that the AOE-6 is as capable as the AOE-1 class in fulfilling the role of battle group station ship. Each class has certain benefits, and liabilities, which they bring to the battle group. The assigned mission of the battle groups in the four generic scenarios did not highlight the higher weapons or stores storage capacities of the AOE-1 class, but instead highlighted the flexibility that the convertible tanks bring to the AOE-6 class. The results for this model are based on the AOE-1 class ships having a cargo fuel mix that contains 40% JP-5/60% DFM. With proper tank alignment, the AOE-1 class can also be configured to carry a 55% JP-5/45% DFM cargo fuel mix. Future plans call for the entire AOE-1 class to undergo an extensive Service Life Extension Program (SLEP) at the end of this century. This SLEP period would provide an excellent opportunity to reconfigure all four ships in the AOE-1 class to support a 55% JP-5/45% DFM cargo fuel mix.

F. CONCLUSIONS

The goal of this thesis was to find the optimal loadout of the Supply class AOE. The goal was sub-divided into two sections; the ordnance loadout and the fuel loadout. For the ordnance loadout, a successful computer model was developed that loaded an AOE-6 in the same fashion as a professional load planner. This computer model, for the first time, actually accounted for and prevented, the loading of incompatible ordnance types in the same cargo holds. This model has the capability, with some enhancements, to be a valuable asset to loading all ordnance carrying ships, not just AOEs. The model highlights the strengths and weaknesses of both the AOE-6 and the AOE-1 class ships.

The second section, to find an optimal fuel mix, demonstrated the inherent flexibility that convertible tanks bring to the AOE-6 class. While every scenario has a different optimal fuel mix, by configuring the AOE-6 to carry roughly 55% JP-5/45% DFM, no change was found in the minimum number of CONSOLs.

The Supply class AOE is an impressive ship design. Many of the shortcomings of the AOE-1 class have been corrected and improved. As the Navy looks to the future, it is easy to see that the AOEs of the Sacramento (AOE 1) and Supply (AOE 6) classes will be the mainstay of the CLF. As such, every effort must be made to improve and upgrade both classes of ship. For the AOE 1 class, this means planning, funding, and executing an ambitious SLEP that will bring this 1950's design, 1960's built class into the 21st century. Areas of improvement include preparing the class for the increase in vertical launch weapons, upgrading the combat survivability, ship's habitability, the ship's weapon systems and UNREP gear.

For the AOE-6, this means ensuring the monorail hoist that is currently planned actually reaches operational status. This class of ship is impressive now, arguably the most capable replenishment ship in the world. Allowing this class to regain the lost 56 feet of length and it will be the premier UNREP ship well into the next century. Think of the force multiplier you would have traveling with each battle group with the world's most capable CLF ship.

G. RECOMMENDATIONS FOR FUTURE STUDY

1. Ordnance Load Model

While this program does an excellent job of loading a few select weapons aboard a single class of ship, several shortcomings will have to be corrected prior to it being of great benefit to the fleet:

1. The program as written is extremely user unfriendly. Only a person with adequate knowledge of GAMS would be able to operate the program should changes in any of the parameters be needed. The recommendation is for the development of a program, using software such as VISUAL BASIC, that would allow for a menu driven version of the load list program. Enhance the program by expanding the program parameters to include the data necessary to load every ordnance carrying ship, including CLF, aircraft carriers and amphibious ship with every type of ordnance, by its Naval Ammunition Logistics Code (NALC), currently in the inventory. This would allow the user to load any ship, with any desired weapon combination. Most of this information is unclassified and readily available at any Naval Weapon Station.

The goal here would be to have a menu driven program that would first give the user the option of selecting which ship class to load. Then the user would be able to input a weapon type (by

NALC), the minimum and maximum number of each weapon type, and the associated priority rating in comparison to the other weapons selected for the loadout. From this information, an initial load list can be generated for review.

2. While the load list program will tell the user on which deck to place each weapon, a method should be developed to tell the user more specifically where on each deck to place the weapon. This would require the program to be expanded to include many of the stowage and dunnage factors involved with ordnance loading aboard ship.

2. Cargo Fuel Model

The Underway Replenishment Department of the Naval Surface Warfare Center, Port Hueneme Division, has been looking at several different options for reducing the total cost of UNREP, without lowering fleet effectiveness [Ref. 4]. With the decommissioning of the AORs and the transfer to MSC of the AE-26 class and the AFS fleet, two options from this study remain viable and worthy of further analysis.

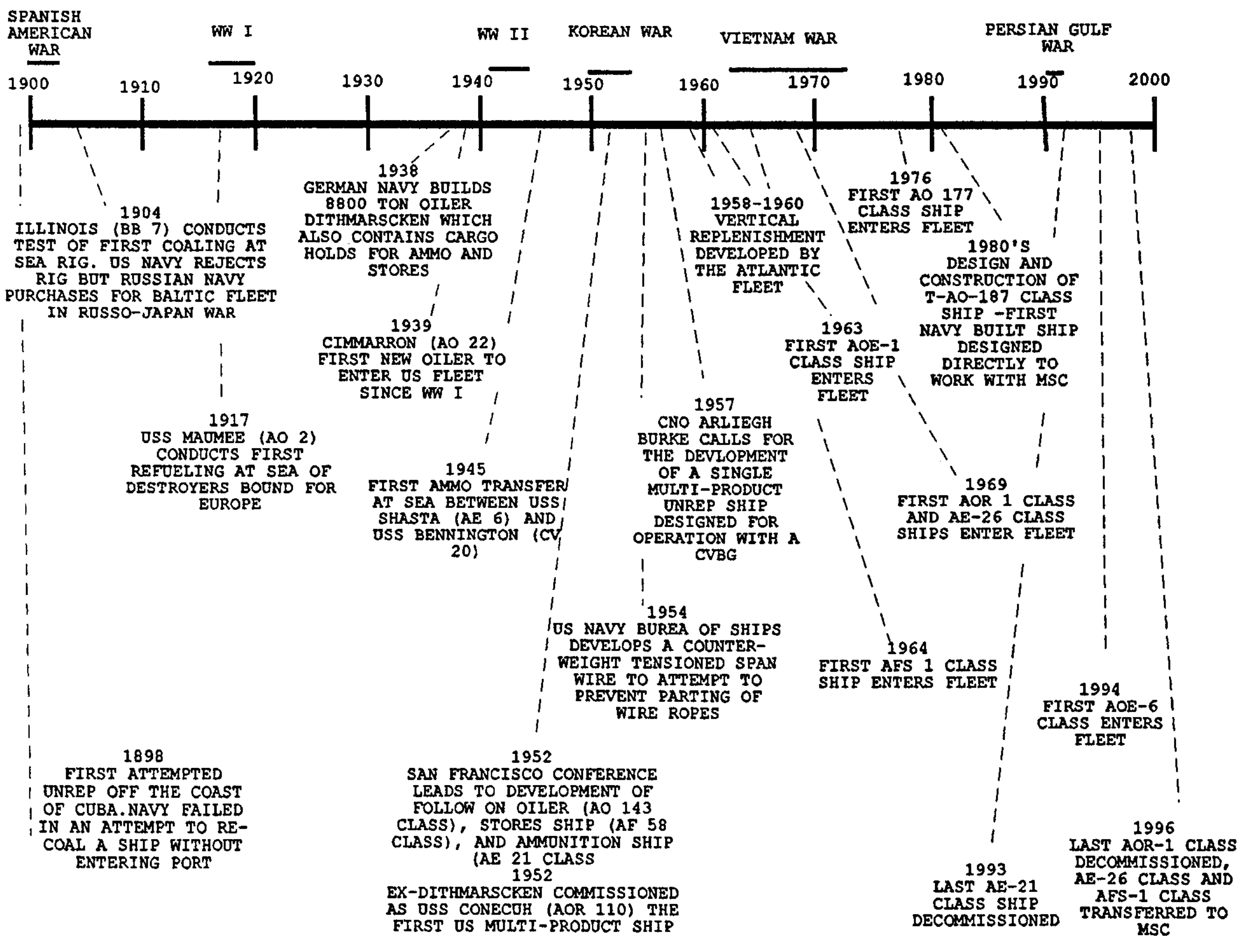
The first option is to "jumboize" the AOE-6 class, similar to the process that the AO-J 177 class recently completed. If the AOE-6 class completed this process, her cargo fuel capacity would increase to 190,000 barrels, or an additional 34,000 barrels. Her cargo stores would increase by 30,000 cubic feet to 120,000 cubic feet, and her cargo ammunition capacity would increase to 367,000 cubic feet [Ref. 4: p. 6]. With a total increase in commodity capacity, the shuttle ship requirement would be reduced. A cost benefit analysis of "jumboizing" the AOE-6 class as compared to the reduced shuttle ship requirement would provide an excellent research opportunity. The AOE-J-6 class could also be substituted into the two models presented in this thesis to demonstrate its expanded capability and usefulness to the fleet.

The second option involves the AOE-1 class. As mentioned in Chapter I, this class of ship has been in service over a quarter of a century. If the Navy intends to keep these ships as assets, a plan must be developed to overhaul and upgrade the entire class.

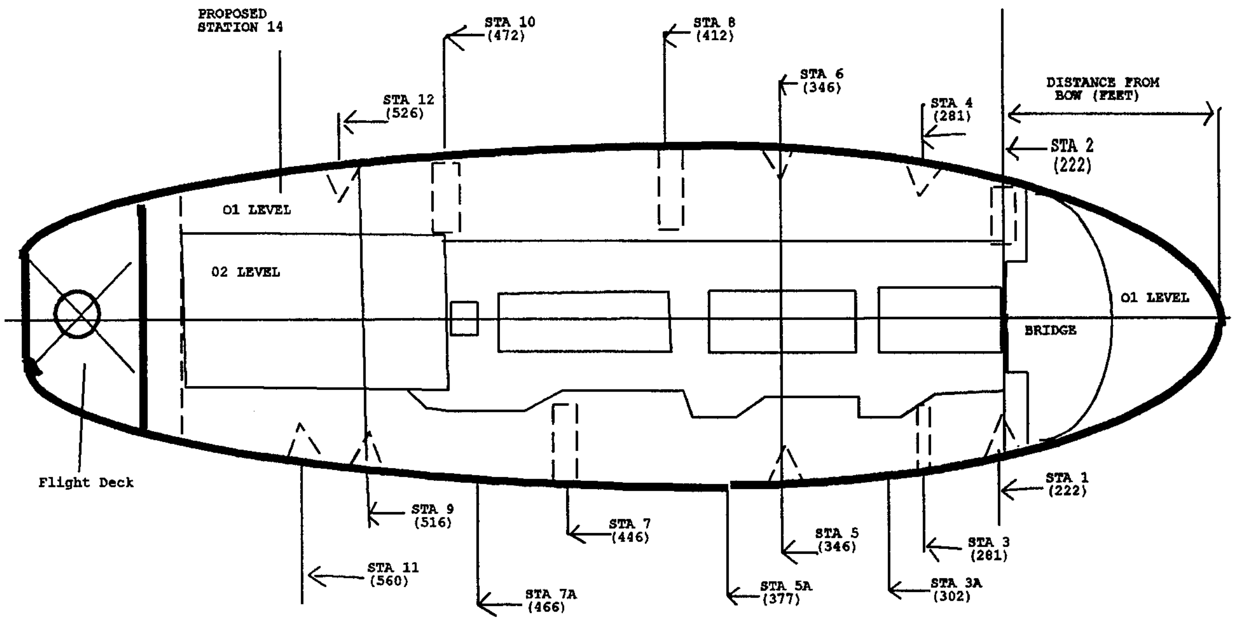
Currently, 200,000 cubic feet of obsolete main deck handling space is not being fully utilized. The AOE-1 was constructed at a time when vertical launch weapons were not in the inventory. An analysis of a plan to upgrade the stores and ammunition storage area could demonstrate the benefit and cost effectiveness of having the entire AOE-1 class placed through a SLEP similar to those undertaken for the fossil fuel aircraft carriers.

The alternative to both of these recommendations is to look at the cargo capacity requirements for the AOE of the future. Based upon the currently planned CLF force for the year 2010, research can be conducted into what size the station ship of the future will have to be in relation to the future size of the CV/CVN BG and the number of shuttle ships available. With no money currently allocated for a follow-on class to the AOE-6, this type of research could possibly influence the design and cost of future ship construction.

APPENDIX A. UNREP DEVELOPMENT TIMELINE



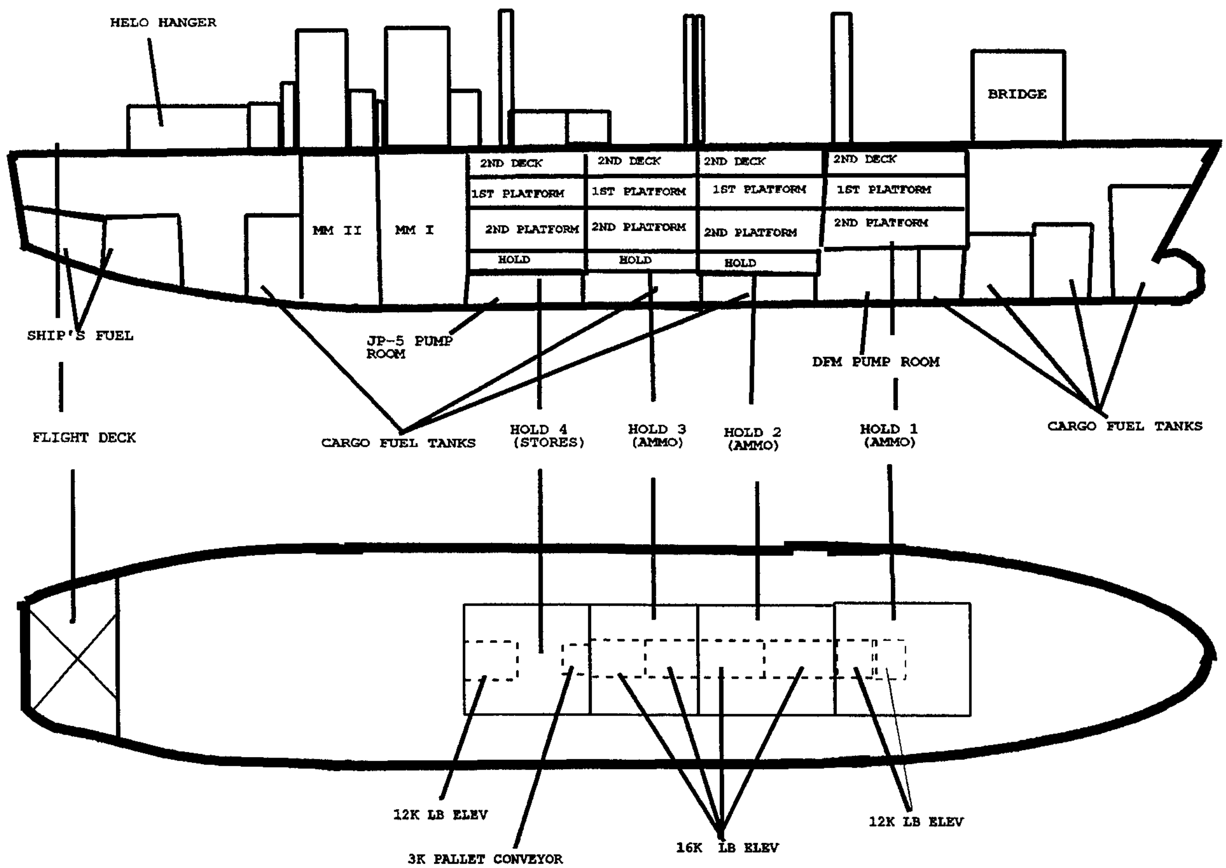
APPENDIX B. USS SUPPLY UNREP STATIONS



AOE-6 (SUPPLY) UNREP CHARACTERISTICS

CARGO STREAM DELIVERY STATIONS (1, 4, 5, 6, 9, 12) 6
CARGO STREAM RECEIVING STATION (11).........................1
FUEL STREAM (DOUBLE HOSE) DELIVERY STATIONS (2, 8, 10).....3
FUEL STREAM (SINGLE HOSE) DELIVERY STATIONS (3, 7).........2
FUEL STREAM (DOUBLE HOSE) RECEIVING STATIONS (3A, 5A, 7A)..3
VERTREP PLATFORM...AFT
HELICOPTERS (VERTREP).....................................2

APPENDIX C. USS SUPPLY AMMUNITION AND CARGO HOLD LAYOUT

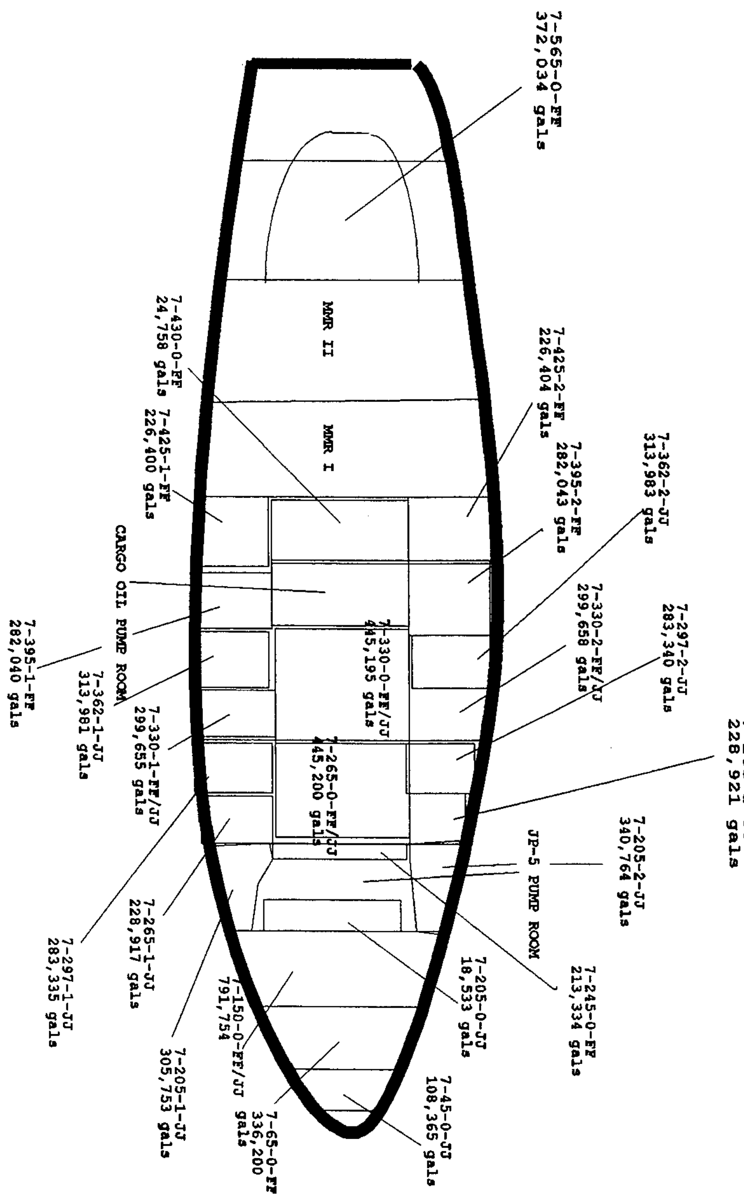


USS SUPPLY CARGO HOLD LAYOUT

LENGTH OVERALL	753 FT
BREADTH	107 FT
FULL LOAD DRAFT	38 FT
FULL LOAD DISPLACEMENT	48,500 TONS
CARGO CAPACITY: ORDNANCE	1800 TONS
DRY STORES	54,000 CU FT
REFRIGERATED STORES	36,400 CU FT
ELEVATORS	4-16K LB CAP 3-12K LB CAP
CONVEYORS	1-3K LB PALLET 3-85 LB PACKAGE

APPENDIX D. USS SUPPLY CARGO FUEL TANK AND PUMP ROOM LAYOUT

USS SUPPLY FUEL TANK CAPACITIES AND CONFIGURATION



APPENDIX E. SURVEY INSTRUCTIONS

1. The following survey is designed to provide a method to determine a prioritization of ordnance to be loaded on an AOE-6 class ship for the scenario outlined in enclosure (2). The data you provide will serve as input to a linear program that will calculate a preferred ordnance load for the AOE-6 given various constraints for loading ordnance on the ship.

2. You are requested to draw on your judgement and experience as a Naval officer in filling out the survey. There are no right or wrong answers, but it is your opinion that counts.

3. Each ordnance type is to be evaluated independently of the other ordnance listed in the survey.

4. Enclosure (3) will allow you an opportunity to make any specific comments you have about the survey.

5. The information gathered from this survey will be used as part of a thesis whose purpose is to optimize the loadout of the new Supply class (AOE-6) multi-product replenishment ship.

6. If you have any questions or desire further information, please contact LT Bill Schmitt at the Operations Analysis Department, Operational Logistics cirriculum of the Naval Postgraduate School (DSN 878-2786).

APPENDIX F. SURVEY

To prevent this scenario from being a classified document, the scenario you are being asked to consider is entirely generic and should not be interpreted as a possible real world enemy's order of battle. You are on the staff of the commander of a carrier battle group (CV/CVN). Your battle group is comprised of the CV and embarked Air Wing, 2 CG-47 (VLS) Ticonderoga class cruisers with embarked LAMPS III, 2 DDG-51 Burke class destroyers, 1 AOE-6 Supply class, 1 DD-963 Spruance class with embarked LAMPS III and 1 DDG-993 Kidd class. You may assume you have the newest models with all the best weaponry. The key is to decide which weapons will be most appropriate to carry out the mission assigned.

The United States is involved in a major regional conflict. Combat operations are underway and the CVBG is cleared to attack any enemy forces within weapons release range. Your AOE-6 class station ship has her minimum loadout of ordnance and will be consoling with an AE to fill her magazines. The CO of the Supply wants to know which weapons to take aboard. You are being asked for your recommendation.

The mission of the CVBG is to conduct strike operations (including naval gunfire support) of enemy bases preceding an amphibious invasion, with a secondary missions of neutralizing enemy submarines, establishing air and sea superiority and attacking possible enemy resupply routes.

Current intelligence indicates a medium ASW threat due to the recent delivery of several diesel submarines, a high ASUW threat comprised mainly of aggressive patrol craft and a high AAW threat largely due to land based cruise missiles. The enemy has good air search radars as well as an adequate air defense missile system.

Determine the contribution to the CVBG mission accomplishment for one additional unit load corresponding to each ordnance type listed below. Assume the ordnance will be loaded on the AOE-6 class ship that already is loaded with a minimum number of each weapon type. You are determining which ordnance is more important to fill remaining capacity of the AOE-6 as you prepare for your mission.

Place a mark in the area under the appropriate category for each ordnance type listed on the following page after reading through the ordnance and unit load lists. Remember to evaluate each ordnance type independently of the others.

ORDNANCE TYPE	VERY LOW	LOW	MEDIUM	HIGH	GREAT
Sidewinder					
Sparrow III					
Phoenix					
SM-2 (Rail Launch)					
Chaff (various types)					
Sonobouys (various types)					
Walleye					
HARM					
Rockeye					
Maverick					
Hellfire					
Harpoon (air launch)					
CIWS ammunition					
Sea Sparrow					
MK 60 (Captor) mine					
MK 46 (ship and air launch)					
ASROC (rail launch)					
2000 lb. bomb					
1000 lb. bomb					
500 lb. bomb					
5' 54 ammunition					

NOTE: A tailored load list for an AOE has over 300 line items for ammunition and ordnance. In order to reduce the scope of the survey you may assume a minimum of every weapon type exists and only weapons that can replenished and fired without entering port were selected for the list.

ROUNDS PER UNIT LOAD

Sidewinder	4
Sparrow III	3
Phoenix	2
SM-2 (Rail Launch)	1
Chaff (various types)	24

Sonobouys (various types)	48
Walleye	1
HARM	2
Rockeye	2
Maverick	1
Hellfire	1
Harpoon (air launch)	1
CIWS ammunition	2400
Sea Sparrow	1
MK 60 (Captor) mine	1
MK 46 (ship and air launch)	2
ASROC (rail launch)	1
2000 lb. bomb	2
1000 lb. bomb	3
500 lb. bomb	6
5' 54 ammunition	39

APPENDIX G. SURVEY INFORMATION

Please complete the following:

1. Present rank ____________ Designator ____________

2. Amount of time on active duty: ______ years

   ______ months

3. Amount of time as a staff officer: ______ years

   _______ months

4. Was the scenario presented in the survey understandable?

   If not, please comment.

5. The ordnance types listed are items that are currently carried by a CVBG. Would you remove any of the items from the list? Would you replace them with a separate item or add another weapon ?

6. Other comments about the survey, including comments about how you responded to the survey:

APPENDIX H
DEMONSTRATION OF OBTAINING SCALE VALUES FROM SURVEY DATA

The steps involved in converting categorical responses to numerical results are listed in Chapter IV. The purpose of this Appendix is to provide the reader with a detailed example of the Lindsay ten-step method.

Prior to starting the ten-step method, first break the large scaling problem down into separate, smaller problems. The purpose of this is to group weapons that appeared to be comparatively judged together [Ref. 11].

STEP 1: Arrange the raw frequency data in a table F_{ij}

PROBLEM 1

F_{ij}	VL	L	M	H	G
Rockeye	0	5	38	22	12
HARM	0	8	25	21	23
1000 lb bomb	1	6	22	30	18

PROBLEM 2

F_{ij}	VL	L	M	H	G
MK-46	12	15	35	13	2
Sidewinder	9	18	24	25	1
SM-2	11	26	18	18	4
Hellfire	11	15	33	16	2
Harpoon	10	26	23	10	8

PROBLEM 3

F_{ij}	VL	L	M	H	G
Phoenix	29	17	20	8	3
ASROC	32	21	19	5	0
MK-60	37	20	16	3	1

PROBLEM 4

F_{ij}	VL	L	M	H	G
Sea Sparrow	4	28	22	18	5
Walleye	2	18	25	25	7
2000 lb bomb	2	17	22	29	7
Sonobouys	4	9	30	28	6
Sparrow	7	16	38	15	1

PROBLEM 5

F_{ij}	VL	L	M	H	G
Chaff	4	8	15	32	18
Maverick	5	10	22	29	11
5' 54 ammo	0	12	26	20	19
CIWS ammo	3	14	18	30	12
500 lb bomb	2	11	20	29	15

STEP 2: The relative cumulative frequencies are computed for each row. The last column will always be a vector of ones and may be omitted. It is also acceptable to compress the table if a low number of survey responders selected a particular category.

PROBLEM 1

P_{ij}	M	H
Rockeye	0.5584	0.8442
HARM	0.4286	0.7013
1000 lb bomb	0.3636	0.7662

PROBLEM 2

P_{ij}	VL	L	M
MK-46	0.1558	0.3506	0.8052
Sidewinder	0.1169	0.3506	0.6623
SM-2	0.1429	0.4805	0.7143
Hellfire	0.1429	0.4675	0.7662
Harpoon	0.1299	0.4675	0.7662

PROBLEM 3

P_{ij}	VL	L
Phoenix	0.3766	0.5974
ASROC	0.4156	0.6883
MK-60	0.4805	0.7403

PROBLEM 4

P_{ij}	L	M
Sea Sparrow	0.4156	0.7013
Walleye	0.2597	0.5844
2000 lb bomb	0.2468	0.5325
Sonobouys	0.1429	0.5584
Sparrow	0.298	0.7922

PROBLEM 5

P_{ij}	L	M	H
Chaff	0.1558	0.3506	0.7662
Maverick	0.1948	0.4805	0.8571
5' 54 ammo	0.1558	0.4935	0.7532
CIWS ammo	0.2208	0.4545	0.8442
500 lb bomb	0.1688	0.4156	0.8052

STEP 3: The relative frequencies are treated as areas under a Normal (0,1) curve. Record the z values from the normal distribution tables in table Z_{ij}.

PROBLEM 1

Z_{ij}	M	H
Rockeye	0.143	1.018
HARM	-0.18	0.532
1000 lb bomb	-0.348	0.733

PROBLEM 2

Z_{ij}	VL	L	M
MK-46	-1.015	-0.348	0.861
Sidewinder	-1.091	-0.384	0.418
SM-2	-1.068	-0.051	0.566
Hellfire	-1.068	-0.084	0.733
Harpoon	-1.232	-0.084	0.733

PROBLEM 3

Z_{ij}	VL	L
Phoenix	-0.314	0.145
ASROC	-0.213	0.492
MK-60	-0.099	0.645

PROBLEM 4

Z_{ij}	L	M
Sea Sparrow	-0.213	0.528
Walleye	-0.643	0.215
2000 lb bomb	-0.685	0.082
Sonobouys	-1.068	0.147
Sparrow	-0.531	0.814

PROBLEM 5

Z_{ij}	L	M	H
Chaff	-1.015	-0.383	0.733
Maverick	-0.861	-0.051	1.068
5' 54 ammo	-1.015	-0.017	0.685
CIWS ammo	-0.769	-0.115	1.018
500 lb bomb	-0.959	-0.213	0.861

STEP 4: Compute the row average $\mathbf{Z_i}$ for each row

STEP 5: Compute the column average b_j for each column. The column averages are the upper bound values for category j on the scale.

PROBLEM 1

Z_{ij}	M	H	Z_i
Rockeye	0.143	1.018	0.581
HARM	-0.18	0.532	0.176
1000 lb bomb	-0.348	0.733	0.193
b_j	-0.128	0.761	

PROBLEM 2

Z_{ij}	VL	L	M	Z_i
MK-46	-1.015	-0.348	0.861	-0.179
Sidewinder	-1.091	-0.384	0.418	-0.352
SM-2	-1.068	-0.051	0.566	-0.184
Hellfire	-1.068	-0.084	0.733	-0.14
Harpoon	-1.232	-0.084	0.733	-0.194
b_j	-1.095	-0.197	0.662	

PROBLEM 3

Z_{ij}	VL	L	Z_i
Phoenix	-0.314	0.145	-0.085
ASROC	-0.213	0.492	0.14
MK-60	-0.099	0.645	0.273
b_j	-0.208	0.427	

PROBLEM 4

Z_{ij}	L	M	Z_i
Sea Sparrow	-0.213	0.528	0.157
Walleye	-0.643	0.215	-0.214
2000 lb bomb	-0.685	0.082	-0.302
Sonobouys	-1.068	0.147	-0.461
Sparrow	-0.531	0.814	0.142
b_j	-0.628	0.357	

PROBLEM 5

Z_{ij}	L	M	H	Z_i
Chaff	-1.015	-0.383	0.733	-0.222
Maverick	-0.861	-0.051	1.068	0.052
5' 54 ammo	-1.015	-0.017	0.685	-0.116
CIWS ammo	-0.769	-0.115	1.018	0.045
500 lb bomb	-0.959	-0.213	0.861	-0.104
b_j	-0.924	-0.156	0.873	

STEP 6: Compute the grand average **b** of all the values in Z_{ij} array. This is done by averaging the column averages. (Problem one mathematics are shown, for the other four problems, only the results are shown)

Problem 1: **b**= ((-.128) + .761)/2 = .317

Problem 2: **b**= -.210

Problem 3: **b**= .110

Problem 4: **b**= .136

Problem 5: **b**= -.069

STEP 7: Compute the sum of squares for the column differences. (Problem one mathematics are shown, for the other four problems, only the results are shown)

Problem 1: $B = ((-.128)-.317)^2 + (.761 - .317)^2 = .395$

Problem 2: B = = 1.543

Problem 3: B = = .201

Problem 4: B = = .633

Problem 5: B = = 1.626

STEP 8: Calculate the sum of squares of the row averages for each Z_{ij} array.

Problem 1: $A_1 = (.143-.581)^2 + (1.018-.581)^2 = .382$

$A_2 =$ = .254

$A_3 =$ = .585

Problem 2: $A_1 = (-1.015-(-.179))^2 + (.-.384-(-.179))^2$

$+ (.861-(-.179))^2 = 1.823$

A_2 = = 1.140

A_3 = = 1.362

A_4 = = 1.626

A_5 = = 1.086

Problem 3: A_1 = = .105

A_2 = = .249

A_3 = = .277

Problem 4: A_1 = = .274

A_2 = = .368

A_3 = = .444

A_4 = = .737

A_5 = = .906

Problem 5: A_1 = = 1.567

A_2 = = 1.878

A_3 = = 1.460

A_4 = = 1.636

A_5 = = 1.505

STEP 9: Calculate the value for sqr(B/A_i) for each row.

Problem 1: From STEP 7, B = .395 for problem 1

From STEP 8, the values of A_i are found

A_1 = .382, A_2 = .254 A_3 = .585

Row 1 = sqr(.395/.382) = 1.017

Row 2 = = 1.247

Row 3 = = .822

Problem 2: From STEP 7, B = 1.543 for problem 2

From STEP 8, the values of A_i are found

A_1 = 1.823, A_2 = 1.140, A_3 = 1.362, A_4 = 1.626

A_5 = 1.086

Row 1 = sqr(1.543/1.823) = .920

Row 2 = = 1.163

Row 3 = = 1.064

Row 4 = = .974

Row 5 = = 1.192

Problem 3: From STEP 7, B = .201 for problem 3

From STEP 8, the values of A_i are found

A_1 = .105, A_2 = .249 A_3 = .277

Row 1 = sqr(.201/.105) = 1.384

Row 2 = = .898

Row 3 = = .851

Problem 4: From STEP 7, B = .633 for problem 4

From STEP 8, the values of A_i are found

A_1 = .274, A_2 = .368, A_3 = .444

A_4 = .737, A_5 = .906

Row 1 = sqr(.633/.274) = 1.520

Row 2 = = 1.312

Row 3 = = 1.194

Row 4 = = .927

Row 5 = = .836

Problem 5: From STEP 7, B = 1.626 for problem 5

From STEP 8, the values of A_i are found

A_1 = 1.567, A_2 = 1.878, A_3 = 1.460

A_4 = 1.636, A_5 = 1.505

Row 1 = sqr(1.626/1.567) = 1.019

Row 2 = = .930

Row 3 = = 1.055

Row 4 = = .997

Row 5 = = 1.039

<u>STEP 10:</u> Find the scale values (S_i) for each row.

(S_i = **b** - [sqr(B/A_i) * $\mathbf{Z_1}$])

Problem 1: From STEP 6, **b** = .317 for problem 1

From STEP 9, the value for sqr(B/A_i) are

Row 1 = 1.017, Row 2 = 1.247, Row 3 = .822,

Row average $\mathbf{Z_1}$ is found in STEP 4

S_1 = .317 - (.581) (1.017) = -.274

S_2 = = .098

S_3 = = .158

Problem 2: From STEP 6, **b** = -.210 for problem 2

From STEP 9, the values for sqr(B/A_i) are

Row 1 = .920, Row 2 = 1.163, Row 3 = 1.064,

Row 4 = .974, Row 5 = 1.192

Row average $\mathbf{Z_1}$ is found in STEP 4

S_1 = -.210 - (-.179) (.920) = -.045

S_2 = = .199

S_3 = = -.014

S_4 = = -.074

S_5 = = .021

Problem 3: From STEP 6, **b** = .110 for problem 3

From STEP 9, the values for sqr(B/A_i) are

Row 1 = 1.384, Row 2 = .898, Row 3 = .851

Row average $\mathbf{Z_1}$ is found in STEP 4

S_1 = .110 - (-.085) (1.384) = .228

S_2 = = -.016

S_3 = = -.122

Problem 4: From STEP 6, **b** = .136 for problem 4

From STEP 9, the values for sqr(B/A_i) are

Row 1 = 1.520, Row 2 = 1.312, Row 3 = 1.194

Row 4 = .927, Row 5 = .836

Row average $\mathbf{Z_1}$ is found in STEP 4

S_1 = .136 - (.157) (1.520) = -.103

S_2 = = .416

S_3 = = .497

S_4 = = .536

S_5 = = .017

Problem 5: From STEP 6, **b** = -.069 for problem 5

From STEP 9, the values for sqr(B/A_i) are

Row 1 = 1.019, Row 2 = .930, Row 3 = 1.055

Row 4 = .997, Row 5 = 1.039

Row average $\mathbf{Z}_1$ is found in STEP 4

S_1 = -.069 - (-.222) (1.019) = .157

S_2 = = -.117

S_3 = = .054

S_4 = = -.113

S_5 = = .039

Now that the scale values have been found for each problem, the values must be converted to a usable scale. Following Rowland [Ref. 9], the transformed scale upper bound values would be 40 for the upper bound of the low category and 80 for the upper bound of the high category. This provides very usable transformed values for employment in the objective function. As stated in Chapter 4, the column averages, $\mathbf{b}_j$, are also that particular problems upper boundary for that column (category). Given the upper boundaries of the low and high categories, look at the problem that contains both of these groups. For this survey sample, problem 5 is the only candidate. From step 4, we know that the scaled value for the high category is .873 while the scaled value for the low category is -.924. The next step is to find the linear transformation to convert .873 to 80 and -.924 to 40. This is accomplished by setting up the two equations and solving for the unknowns.

$$\alpha + \beta\,(.873) = 80$$

$$\alpha + \beta\,(-.924) = 40$$

Solving the equations for the two unknowns yields: $\alpha = 60.57$

$\beta = 22.26$

This leads to the linear transformation of 60.57 + 22.26 (X), where X is the scaled value S_i. After completing the linear transformation on all scaled values, including the upper bounds on all of the available categories, a user will now have transformed values for the upper bound of each of the categories. These transformed upper bound values enable the user to go through each of the remaining problems and transform the scaled values. The following are the linear transformations used in the five problems:

Problem 1: 60.40 + 25.76 (X)

Problem 2: 43.92 + 19.91 (X)

Problem 3: 28.00 + 28.20 (X)

Problem 4: 50.90 + 17.40 (X)

Problem 5: 60.57 + 22.26 (X)

Table 16 in Chapter IV shows the final transformed results.

APPENDIX I
SUPPLY (AOE 6) ORDNANCE LOAD MODEL GAMS PROGRAM AND RESULTS

```
-----------GAMS AND DOLLAR CONTROL OPTIONS---------------------

OPTIONS
LIMCOL =  0  , LIMROW  =  0   , SOLPRINT = OFF , DECIMALS = 2
RESLIM = 20000, ITERLIM = 25000, OPTCR    = 0.05 , SEED  = 3141;
*-------------------------------------------------------------
* This GAMS linear program was developed to load an AOE-6 class
* fast combat stores ship with ordnance.  It is the first part
* of a two program model to optimize the loadout of all
* commodities aboard this new class of ship.  This program is
* designed to reflect the actual limitations fleet load planners
* are forced to work with during ordnance loadouts.
*
* The output of this GAMS program indicates how much ordnance
* and associated accessories should be stored on each deck to
* maximize the objective function and meet all constraints.  The
* primary constraints modeled are weight (deck stress), volume,
* ordnance compatibility and ship stability (load heavy low and
* forward).
*
* The following ordnance abbreviations are used in this
* program:
* SID - SIDEWINDER missile, SPA - SPARROW missile, PHO - PHOENIX
* missile, SM2 - STANDARD missile, CHF - CHAFF rounds, SNB -
* SONOBOUYS, WAL - WALLEYE glide bomb, HRM - HARM missile, RCK -
* ROCKEYE cluster bomb, MVK - MAVERICK missile, HLF - HELLFIRE
* missile, HAR - HARPOON cruise missile, CWS - CIWS 20MM
* ammunition, SSP - SEA SPARROW missile, M60 - MK60 captor mine,
* M46 - MK46 torpedo, ASR - ASROC rocket, 2LB - 2000 LB bomb, 1LB
* - 1000 LB bomb, 5LB - 500 LB bomb, PRO - 5in 54 projectiles.
*
* The following ordnance accessory abbreviations are used in this
* program:
* IA - ignitor assembly, WA - wing assembly, WF - wing and fin
* assembly,F - fins, C - charge, W -wings
* NOTE: This is by no means an exhaustive list of all
* accessories, but a demonstration of the ability to match a
* weapon with an additional requirement.  Most weapons now can be
* shipped and ordered in all up rounds (AUR).
*
*    The following is the deck arrangement for this program:
*                1st Ammo Hold   2nd Ammo Hold    3rd Ammo Hold
* 2nd Deck        DECK1           DECK4            DECK8
* 1st Platform    DECK2           DECK5            DECK9
* 2nd Platform    DECK3           DECK6            DECK10
* Hold            _____           DECK7            DECK11
*
**************************SETS**********************************
```

```
SETS
 W  types of weapons /SID, SPA, PHO, SM2, CHF, SNB, WAL, HRM,
                  RCK, MVK, HLF, HAR, CWS, SSP, M60, M46, ASR,
                  2LB, 1LB, 5LB, PRO/

 D  number of decks    /DECK1 * DECK11/

AC  weapon accessory  /WALWF, HARF, HARW, M46IA,
                       ASRIA, 2LBF, 1LBF, 5LBF, PROC/

C   compatibility type /A,B,C,D,E,F,G,H,J,K,L,N,S,INRT/

TYPEW(C)
TYPEWP(C);

ALIAS (C,I,J);
ALIAS(W,WP);

SCALAR M just a big number to use in the program /200/;


*********************PARAMETERS*********************************
PARAMETER VOL(W)   volume of each weapon unit round in cubic feet
       /SID      52
        SPA      93
        PHO      111
        SM2      92
        CHF      35
        SNB      50
        WAL      85
        HRM      94
        RCK      62
        MVK      53
        HLF      70
        HAR      120
        CWS      40
        SSP      39
        M60      102
        M46      28
        ASR      105
        2LB      55
        1LB      36
        5LB      33
        PRO      38 /;

 PARAMETER ACCVOL(AC)  volume of accessories in cubic feet
       /WALWF    72
        HARW     1
        HARF     6
        M46IA    1
        ASRIA    1
        2LBF     58
```

```
        1LBF     42
        5LBF     62
        PROC     44   /;

PARAMETER WT(W)    weight of ordnance unit load in lbs divided by
                                                          1000
        /SID      1.41
         SPA      2.018
         PHO      2.975
         SM2      2.081
         CHF      1.180
         SNB      1.35
         WAL      2.95
         HRM      2.4
         RCK      1.687
         MVK      1.13
         HLF      1.195
         HAR      3.389
         CWS      2.21
         SSP      .848
         M60      3.006
         M46      .809
         ASR      1.702
         2LB      4.075
         1LB      2.974
         5LB      3.146
         PRO      3.732 /;

 PARAMETER ACCWT(AC)   weight of accessory unit load in lbs
                    divided by 1000
        /WALWF    1.153
         HARW     .0001
         HARF     .0068
         M46IA    .085
         ASRIA    .085
         2LBF     .814
         1LBF     .74
         5LBF     1.094
         PROC     1.848 /;

 PARAMETER BENEFIT(W)   this is developed from survey responses
 * determined from fleet survey results discussed in chapter 4
        /SID      47.9
         SPA      51.2
         PHO      34.4
         SM2      43.6
         CHF      64.1
         SNB      60.7
         WAL      58.1
         HRM      62.9
         RCK      53.3
         MVK      58.0
```

```
       HLF      42.4
       HAR      44.3
       CWS      58.1
       SSP      49.1
       M60      24.6
       M46      43.0
       ASR      27.5
       2LB      59.5
       1LB      64.5
       5LB      61.4
       PRO      61.8 /;

 PARAMETER COMP(W,C)    compatibility of weapon
      /SID.E    1
       SPA.E    1
       PHO.E    1
       SM2.E    1
       CHF.S    1
       SNB.S    1
       WAL.D    1
       HRM.E    1
       RCK.D    1
       MVK.E    1
       HLF.E    1
       HAR.J    1
       CWS.C    1
       SSP.E    1
       M60.D    1
       M46.E    1
       ASR.E    1
       2LB.D    1
       1LB.D    1
       5LB.D    1
       PRO.D    1    /;

 PARAMETER CUBE(D)    usable area for storage each deck in cubic
                                                          feet
* these figures are the actual measured volumes and are used by
* the load planners at NWS, Earle
      /DECK1      12300
       DECK2      12300
       DECK3      12200
       DECK4      13600
       DECK5      13600
       DECK6      11900
       DECK7      11800
       DECK8      12550
       DECK9      13600
       DECK10     11600
       DECK11     11500 /;

PARAMETER STRESS(D)  area of deck times allowable stress div by
```

```
                        1000 in lbs

     /DECK1      1065
      DECK2      1420
      DECK3      1609
      DECK4      1165
      DECK5      1554
      DECK6      1553
      DECK7      1554
      DECK8      1165
      DECK9      1154
      DECK10     1530
      DECK11     1517  /;

PARAMETER MINWEAP(W)  minimum numbers of weapons to load
     /SID       10
      SPA       10
      PHO       10
      SM2       10
      CHF       10
      SNB       10
      WAL       10
      HRM       10
      RCK       10
      MVK       10
      HLF       10
      HAR       10
      CWS       10
      SSP       10
      M60       10
      M46       10
      ASR       10
      2LB       10
      1LB       10
      5LB       10
      PRO       10   /;

PARAMETER MAXWEAP(W)  maximum numbers of weapons to load
     /SID       90
      SPA       20
      PHO       20
      SM2       20
      CHF       150
      SNB       150
      WAL       150
      HRM       200
      RCK       150
      MVK       150
      HLF       75
      HAR       15
      CWS       80
      SSP       25
```

```
          M60      25
          M46      15
          ASR      15
          2LB      250
          1LB      250
          5LB      250
          PRO      150   /;

   PARAMETER REQACC(W,AC) bring along the required accessories
         /WAL.WALWF    1
          HAR.HARW     1
          HAR.HARF     1
          M46.M46IA    1
          ASR.ASRIA    1
          2LB.2LBF     1
          1LB.1LBF     1
          5LB.5LBF     1
          PRO.PROC     1 /;

  SCALAR STFACT  stow factor  /1/;
* The stow factor is built into the usable cube by NWS Earle.
* This comment is here to remind user  to account for stow factor
* during planning.

   TABLE MIX(C,C) design table to check for weapons compatibility

          A   B   C   D   E   F   G   H   J   K   L   N   S   INRT
    A     1   0   0   0   0   0   0   0   0   0   0   0   0   1
    B     0   1   0   0   0   0   0   0   0   0   0   0   1   1
    C     0   0   1   1   1   0   0   0   0   0   0   1   1   1
    D     0   0   1   1   1   0   0   0   0   0   0   1   1   1
    E     0   0   1   1   1   0   0   0   0   0   0   1   1   1
    F     0   0   0   0   0   1   0   0   0   0   0   0   1   1
    G     0   0   0   0   0   0   1   0   0   0   0   0   1   1
    H     0   0   0   0   0   0   0   1   0   0   0   0   1   1
    J     0   0   0   0   0   0   0   0   1   0   0   0   1   1
    K     0   0   0   0   0   0   0   0   0   1   0   0   1   1
    L     0   0   0   0   0   0   0   0   0   0   1   0   0   1
    N     0   0   1   1   1   0   0   0   0   0   0   1   1   1
    S     0   1   1   1   1   1   1   1   1   1   0   1   1   1
   INRT   1   1   1   1   1   1   1   1   1   1   1   1   1   1  ;

* This section will create table WEPCMP that will show which
* weapons are compatible and able to be stored in the same
* compartments!

   PARAMETER WEPCMP(W,WP);

   WEPCMP(W,WP) = 0;

   LOOP (W,
      TYPEW(C) = NO;
```

```
    TYPEW(C) = YES $ (COMP(W,C) EQ 1);
    LOOP (WP,
       TYPEWP(C) = NO;
       TYPEWP(C) = YES $ (COMP(WP,C) EQ 1);
       WEPCMP(W,WP) = 1 $ (sum((TYPEW,TYPEWP),
                                  MIX (TYPEW,TYPEWP)) EQ 1 );
    );
  );


************************VARIABLES*******************************
  POSITIVE VARIABLES
    ACC (W,AC,D)  accessories for each weapon and deck stored on
   STORES (W,D)     ordnance on each deck of type w      ;

 BINARY VARIABLE
   YSTORES (W,D)  yes or no if weapon type stored on that deck ;

 VARIABLES
   Z                total benefit of ordnance load;


************************EQUATIONS********************************
 EQUATIONS
   OBJ              max objective function
   LIMCUBE(D)       do not exceed cubic feet avail on each deck
   WTLIMIT(D)       do not exceed deck stress
   MINLOAD(W)       make sure you load the minimum amount of
                  each weapon
   MAXLOAD(W)       don't bring more weapons then your allowed
   NEEDACC(W,AC)    observe the ordnance accessory requirement

 * The next four constraints model how load planners actually
 * plan to load ships. The goal of every load planner is to have
* the most wt low and forward on the ship for sea-keeping
 * purposes.  This aspect of the model is very important for AE's
 * but also effects the AOE's when they are low on cargo fuel
 * (DFM and JP-5).  Due to the number system (DECK1 etc)
 * and each ship class DECK7 means a different deck, it is to
 * difficult to formulate this in a compact fashion. STAB1 & STAB
 * 2 are designed to load the ship heaviest forward, while STAB 3
 * & 4 load it heaviest down low.

    STAB1            ensure the heaviest load is in 1st hold
    STAB2            ensure the next heaviest load is on 2nd hold
    STAB3            the hold and 2nd plat are heaviest
    STAB4            1st plat heavier then 2nd deck
    WEPPRES(W,D)     see if weapon is present on deck
    CMP(W,WP,D)      ensure compatible ammo on each deck;
```

```
 OBJ..              sum(D, sum(W, BENEFIT(W) * STORES(W,D))) =E= Z;
 LIMCUBE(D)..       sum(W, VOL(W) * STORES(W,D)) +
                    sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                    ACCVOL(AC)*ACC(W,AC,D)) ) =L= CUBE(D) * STFACT;
 WTLIMIT(D)..       sum(W, WT(W) * STORES(W,D)) +
                    sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                    ACCWT(AC)*ACC(W,AC,D)) ) =L= STRESS(D);

* The min and max loads are subjective.  These numbers were found
* by trial and error

MINLOAD(W)..       sum(D, STORES(W,D)) =G= MINWEAP(W);
MAXLOAD(W)..       sum(D, STORES(W,D)) =L= MAXWEAP(W);
NEEDACC(W,AC) $ (REQACC(W,AC) GT 0).. sum(D, ACC(W,AC,D)) =G=
                    REQACC(W,AC) * sum (D,STORES(W,D));

 STAB1..              sum(W, WT(W) * STORES(W,'DECK1'))
                    + sum(W, WT(W) * STORES(W,'DECK2'))
                    + sum(W, WT(W) * STORES(W,'DECK3'))  =G=
                      sum(W, WT(W) * STORES(W,'DECK4'))
                    + sum(W, WT(W) * STORES(W,'DECK5'))
                    + sum(W, WT(W) * STORES(W,'DECK6'))
                    + sum(W, WT(W) * STORES(W,'DECK7')) ;

 STAB2..              sum(W, WT(W) * STORES(W,'DECK4'))
                    + sum(W, WT(W) * STORES(W,'DECK5'))
                    + sum(W, WT(W) * STORES(W,'DECK6'))
                    + sum(W, WT(W) * STORES(W,'DECK7'))  =G=
                      sum(W, WT(W) * STORES(W,'DECK8'))
                    + sum(W, WT(W) * STORES(W,'DECK9'))
                    + sum(W, WT(W) * STORES(W,'DECK10'))
                    + sum(W, WT(W) * STORES(W,'DECK11')) ;

 STAB3..              sum(W, WT(W) * STORES(W,'DECK3'))
                    + sum(W, WT(W) * STORES(W,'DECK6'))
                    + sum(W, WT(W) * STORES(W,'DECK7'))
                    + sum(W, WT(W) * STORES(W,'DECK10'))
                    + sum(W, WT(W) * STORES(W,'DECK11')) =G=
                      sum(W, WT(W) * STORES(W,'DECK1'))
                    + sum(W, WT(W) * STORES(W,'DECK2'))
                    + sum(W, WT(W) * STORES(W,'DECK4'))
                    + sum(W, WT(W) * STORES(W,'DECK5'))
                    + sum(W, WT(W) * STORES(W,'DECK8'))
                    + sum(W, WT(W) * STORES(W,'DECK9')) ;

 STAB4..              sum(W, WT(W) * STORES(W,'DECK2'))
                    + sum(W, WT(W) * STORES(W,'DECK5'))
                    + sum(W, WT(W) * STORES(W,'DECK9')) =G=
                    + sum(W, WT(W) * STORES(W,'DECK1'))
                    + sum(W, WT(W) * STORES(W,'DECK4'))
                    + sum(W, WT(W) * STORES(W,'DECK8')) ;
```

```
WEPPRES(W,D)..  YSTORES(W,D)*M =G=   STORES(W,D);

CMP(W,WP,D) $ (WEPCMP(W,WP) EQ 0)..
               STORES(WP,D) =L= M * (1 - YSTORES(W,D));

MODEL AOE6/ALL/;

SOLVE AOE6 USING MIP MAXIMIZING Z;

PARAMETER NUMWEPS(W),NUMACC(W,AC);

NUMWEPS(W)  = sum(D,STORES.L(W,D));
NUMACC(W,AC)  = sum(D, ACC.L(W,AC,D));

PARAMETERS VOLUSE(D),WTUSE(D);

VOLUSE(D)  = sum(W, VOL(W) * STORES.L(W,D)) +
                 sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                ACCVOL(AC)*ACC.L(W,AC,D)));
WTUSE(D)  =  sum(W, WT(W) * STORES.L(W,D)) +
                 sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                 ACCWT(AC)*ACC.L(W,AC,D)));

PARAMETER TONS;
TONS = (sum(D, WTUSE(D)) * 1000) / 2240;

DISPLAY WEPCMP;
DISPLAY STORES.L,ACC.L;
DISPLAY NUMWEPS,NUMACC;
DISPLAY VOLUSE,WTUSE;
DISPLAY TONS;


          S O L V E      S U M M A R Y

     MODEL      AOE6          OBJECTIVE      Z
     TYPE       MIP           DIRECTION      MAXIMIZE
     SOLVER     XA            FROM LINE      415

**** SOLVER STATUS             1 NORMAL COMPLETION
**** MODEL STATUS              8 INTEGER SOLUTION
**** OBJECTIVE VALUE                109972.8734

                          ABSOLUTUE                  RELATIVE
ACTUAL DISTANCE           998.20185                   0.00900
TOLERANCES (OPTCA)          0.0000           (OPTCR)  0.5000


----     434 PARAMETER WEPCMP

     SID          SPA          PHO          SM2          CHF      SNB
```

SID	1.00	1.00	1.00	1.00	1.00	1.00
SPA	1.00	1.00	1.00	1.00	1.00	1.00
PHO	1.00	1.00	1.00	1.00	1.00	1.00
SM2	1.00	1.00	1.00	1.00	1.00	1.00
CHF	1.00	1.00	1.00	1.00	1.00	1.00
SNB	1.00	1.00	1.00	1.00	1.00	1.00
WAL	1.00	1.00	1.00	1.00	1.00	1.00
HRM	1.00	1.00	1.00	1.00	1.00	1.00
RCK	1.00	1.00	1.00	1.00	1.00	1.00
MVK	1.00	1.00	1.00	1.00	1.00	1.00
HLF	1.00	1.00	1.00	1.00	1.00	1.00
HAR					1.00	1.00
CWS	1.00	1.00	1.00	1.00	1.00	1.00
SSP	1.00	1.00	1.00	1.00	1.00	1.00
M60	1.00	1.00	1.00	1.00	1.00	1.00
M46	1.00	1.00	1.00	1.00	1.00	1.00
ASR	1.00	1.00	1.00	1.00	1.00	1.00
2LB	1.00	1.00	1.00	1.00	1.00	1.00
1LB	1.00	1.00	1.00	1.00	1.00	1.00
5LB	1.00	1.00	1.00	1.00	1.00	1.00
PRO	1.00	1.00	1.00	1.00	1.00	1.00

+	WAL	HRM	RCK	MVK	HLF	HAR
SID	1.00	1.00	1.00	1.00	1.00	
SPA	1.00	1.00	1.00	1.00	1.00	
PHO	1.00	1.00	1.00	1.00	1.00	
SM2	1.00	1.00	1.00	1.00	1.00	
CHF	1.00	1.00	1.00	1.00	1.00	1.00
SNB	1.00	1.00	1.00	1.00	1.00	1.00
WAL	1.00	1.00	1.00	1.00	1.00	
HRM	1.00	1.00	1.00	1.00	1.00	
RCK	1.00	1.00	1.00	1.00	1.00	
MVK	1.00	1.00	1.00	1.00	1.00	
HLF	1.00	1.00	1.00	1.00	1.00	
HAR						1.00
CWS	1.00	1.00	1.00	1.00	1.00	
SSP	1.00	1.00	1.00	1.00	1.00	
M60	1.00	1.00	1.00	1.00	1.00	
M46	1.00	1.00	1.00	1.00	1.00	
ASR	1.00	1.00	1.00	1.00	1.00	
2LB	1.00	1.00	1.00	1.00	1.00	
1LB	1.00	1.00	1.00	1.00	1.00	
5LB	1.00	1.00	1.00	1.00	1.00	
PRO	1.00	1.00	1.00	1.00	1.00	

434 PARAMETER WEPCMP

+	CWS	SSP	M60	M46	ASR	2LB
SID	1.00	1.00	1.00	1.00	1.00	1.00

SPA	1.00	1.00	1.00	1.00	1.00	1.00
PHO	1.00	1.00	1.00	1.00	1.00	1.00
SM2	1.00	1.00	1.00	1.00	1.00	1.00
CHF	1.00	1.00	1.00	1.00	1.00	1.00
SNB	1.00	1.00	1.00	1.00	1.00	1.00
WAL	1.00	1.00	1.00	1.00	1.00	1.00
HRM	1.00	1.00	1.00	1.00	1.00	1.00
RCK	1.00	1.00	1.00	1.00	1.00	1.00
MVK	1.00	1.00	1.00	1.00	1.00	1.00
HLF	1.00	1.00	1.00	1.00	1.00	1.00
CWS	1.00	1.00	1.00	1.00	1.00	1.00
SSP	1.00	1.00	1.00	1.00	1.00	1.00
M60	1.00	1.00	1.00	1.00	1.00	1.00
M46	1.00	1.00	1.00	1.00	1.00	1.00
ASR	1.00	1.00	1.00	1.00	1.00	1.00
2LB	1.00	1.00	1.00	1.00	1.00	1.00
1LB	1.00	1.00	1.00	1.00	1.00	1.00
5LB	1.00	1.00	1.00	1.00	1.00	1.00
PRO	1.00	1.00	1.00	1.00	1.00	1.00

+	1LB	5LB	PRO
SID	1.00	1.00	1.00
SPA	1.00	1.00	1.00
PHO	1.00	1.00	1.00
SM2	1.00	1.00	1.00
CHF	1.00	1.00	1.00
SNB	1.00	1.00	1.00
WAL	1.00	1.00	1.00
HRM	1.00	1.00	1.00
RCK	1.00	1.00	1.00
MVK	1.00	1.00	1.00
HLF	1.00	1.00	1.00
CWS	1.00	1.00	1.00
SSP	1.00	1.00	1.00
M60	1.00	1.00	1.00
M46	1.00	1.00	1.00
ASR	1.00	1.00	1.00
2LB	1.00	1.00	1.00
1LB	1.00	1.00	1.00
5LB	1.00	1.00	1.00
PRO	1.00	1.00	1.00

---- 435 VARIABLE STORES.L ordnance on each deck of type w

	DECK1	DECK2	DECK3	DECK4	DECK5	DECK6
PHO		10.00				
CHF		150.00				
SNB	96.89					
MVK					123.42	
HAR				10.00		

SSP					25.00
ASR			10.00		
2LB			143.81		
1LB	92.40			157.60	
5LB	149.61				
PRO					150.00

+	DECK7	DECK8	DECK9	DECK10	DECK11
SID				90.00	
SPA			20.00		
SM2			10.00		
SNB		53.11			
WAL					10.00
HRM	125.53				
RCK				38.06	111.94
MVK		16.95			9.62
HLF			75.00		
CWS					80.00
M60			10.00		
M46			15.00		
5LB		151.80			

---- 435 VARIABLE ACC.L accessories for each weapon and deck stored on

	DECK1	DECK2	DECK4	DECK5	DECK6
M46.M46IA			15.00		
ASR.ASRIA				10.00	
2LB.2LBF	71.19				
1LB.1LBF		141.43			
5LB.5LBF			199.76		
PRO.PROC				31.25	118.75

+	DECK8	DECK9	DECK10
WAL.WALWF	10.00		
HAR.HARF	10.00		
HAR.HARW	10.00		
2LB.2LBF	55.12	17.50	
1LB.1LBF			108.57
5LB.5LBF		50.24	

---- 436 PARAMETER NUMWEPS number of weapons in final load

```
SID  90.00, SPA  20.00, PHO  10.00, SM2  10.00,    CHF 150.00
SNB 150.00, WAL  10.00, HRM 125.53, RCK 150.00,    MVK 150.00
HLF  75.00, HAR  10.00, CWS  80.00, SSP  25.00,    M60  10.00
M46  15.00, ASR  10.00, 2LB 143.81, 1LB 250.00,    5LB 250.00
```

PRO 150.00

---- 436 PARAMETER NUMACC number of accessories in final load

	WALWF	HARF	HARW	M46IA	ASRIA	2LBF
WAL	10.00					
HAR		10.00	10.00			
M46				15.00		
ASR					10.00	
2LB						143.81

+	1LBF	5LBF	PROC
1LB	250.00		
5LB		250.00	
PRO			150.00

---- 437 PARAMETER VOLUSE total volume of final loadout

DECK1 12300.00, DECK2 12300.00, DECK3 12200.00, DECK4 13600.00
DECK5 13600.00, DECK6 11900.00, DECK7 11800.00, DECK8 12550.00
DECK9 13600.00, DECK10 11600.00, DECK11 11500.00

---- 437 PARAMETER WTUSE total weight of load on each deck divided by 1000lbs

DECK1 463.56, DECK2 311.41, DECK3 911.97, DECK4 253.70
DECK5 666.76, DECK6 800.45, DECK7 301.28, DECK8 624.87
DECK9 262.20, DECK10 271.46, DECK11 406.01

---- 438 PARAMETER TONS total tonnage of loadout = 2354.31

APPENDIX J
SEATTLE (AOE 3) ORDNANCE LOAD MODEL GAMS PROGRAM AND RESULTS

```
*-----------GAMS AND DOLLAR CONTROL OPTIONS---------------------

OPTIONS
LIMCOL =  0   , LIMROW  =  0    , SOLPRINT = OFF , DECIMALS = 2
RESLIM = 20000, ITERLIM = 50000, OPTCR     = 0.05 , SEED  = 3141;
*----------------------------------------------------------------
*  This program will substitute the storage constarints of the
*  AOE-3 for the AOE-6 and provide a direct comparison of the
*  number of weapons that can be carried.
*  The output of this GAMS program indicates how much ordnance
*  and associated accessories should be stored on each deck to
*  maximze the objective function and meet all constraints.  The
*  primary constraints modeled are weight (deck stress), volume,
*  ordnance compatabilty and ship stability (load heavy low and
*  forward).
*
*    The ordnance abbreviations remain the same as those
*  used in the AOE-6 program:
*    The following is the deck arrangement for this program:
*               1st Hold   2nd Hold  3rd Hold  4rth Hold
* 2nd Deck        DECK1      DECK6     DECK11    DECK16
* 1st Platform    DECK2      DECK7     DECK12    DECK17
* 2nd Platform    DECK3      DECK8     DECK13    DECK18
* 3rd Platform    DECK4      DECK9     DECK14    DECK19
* Hold            DECK5      DECK10    DECK15    DECK20
*
**************************SETS***********************************

* SETS, Scalars and Alias remain the same as those in the AOE-6
* Program and are omitted

******************PARAMAETERS************************************

* Only the parameters that change from the AOE-6 program will be
* shown.  All other parameters tabels, loops etc. remain the
* same.


 PARAMETER CUBE(D)   usable area for storage ech deck in cubic
feet
       /DECK1      12672
        DECK2      12672
        DECK3      12672
        DECK4      12672
        DECK5       6600
        DECK6       9690
        DECK7       9690
        DECK8       9690
        DECK9       9690
```

```
        DECK10      9690
        DECK11     12672
        DECK12     12672
        DECK13     12672
        DECK14     12672
        DECK15     12672
        DECK16      9690
        DECK17      9690
        DECK18      9690
        DECK19      9690
        DECK20      9690 /;

PARAMETER STRESS(D)  area of deck times allowable stress div by
1000 in lbs
       /DECK1       748
        DECK2      1282
        DECK3      1282
        DECK4      1282
        DECK5      1011
        DECK6       370
        DECK7       635
        DECK8       635
        DECK9       635
        DECK10      952
        DECK11      748
        DECK12     1282
        DECK13     1282
        DECK14     1282
        DECK15     1922
        DECK16      370
        DECK17      635
        DECK18      635
        DECK19      635
        DECK20      952 /;

************************VARIABLES*******************************

* all variables remain the same

************************EQUATIONS*******************************

* all equations remain the same with the exception of additional
* stability constraints to reflect the different hold
* configuration of the AOE-3


* The next six constraints model how load planners actually plan
* to load ships. The goal of every load planner is to have the
* most wt low and forward on the ship for sea-keeping purposes.
* This aspect of the model is very important for AE's but also
* effects the AOE's when they are low on cargo fuel (DFM and
```

```
*  (JP-5).  Due to the number system (DECK1 etc)
* and each ship class DECK7 means a different deck, it is to
* difficult to formulate this in a compact fashion. STAB1 & STAB
* 2 are designed to load the ship heaviest forward, while STAB 3
* 4, 5 and 6 load it heaviest down low.
STAB1          ensure the heaviest load is in 1st & 2ND Holds
STAB2          ensure the next heaviest load is in the 3rd hold
STAB3          the hold and 3rd plat are heaviest
STAB4          ensure 3rd plat heavier then 2nd
STAB5          ensure 2nd plat heavier then 1st plat
STAB6          1st plat heavier then 2nd deck

 STAB1..          sum(W, WT(W) * STORES(W,'DECK1'))
                + sum(W, WT(W) * STORES(W,'DECK2'))
                + sum(W, WT(W) * STORES(W,'DECK3'))
                + sum(W, WT(W) * STORES(W,'DECK4'))
                + sum(W, WT(W) * STORES(W,'DECK5'))
                + sum(W, WT(W) * STORES(W,'DECK6'))
                + sum(W, WT(W) * STORES(W,'DECK7'))
                + sum(W, WT(W) * STORES(W,'DECK8'))
                + sum(W, WT(W) * STORES(W,'DECK9'))
                + sum(W, WT(W) * STORES(W,'DECK10')) =G=
                  sum(W, WT(W) * STORES(W,'DECK11'))
                + sum(W, WT(W) * STORES(W,'DECK12'))
                + sum(W, WT(W) * STORES(W,'DECK13'))
                + sum(W, WT(W) * STORES(W,'DECK14'))
                + sum(W, WT(W) * STORES(W,'DECK15'))
                + sum(W, WT(W) * STORES(W,'DECK16'))
                + sum(W, WT(W) * STORES(W,'DECK17'))
                + sum(W, WT(W) * STORES(W,'DECK18'))
                + sum(W, WT(W) * STORES(W,'DECK19'))
                + sum(W, WT(W) * STORES(W,'DECK20')) ;


 STAB2..          sum(W, WT(W) * STORES(W,'DECK11'))
                + sum(W, WT(W) * STORES(W,'DECK12'))
                + sum(W, WT(W) * STORES(W,'DECK13'))
                + sum(W, WT(W) * STORES(W,'DECK14'))
                + sum(W, WT(W) * STORES(W,'DECK15')) =G=
                  sum(W, WT(W) * STORES(W,'DECK16'))
                + sum(W, WT(W) * STORES(W,'DECK17'))
                + sum(W, WT(W) * STORES(W,'DECK18'))
                + sum(W, WT(W) * STORES(W,'DECK19'))
                + sum(W, WT(W) * STORES(W,'DECK20')) ;

 STAB3..          sum(W, WT(W) * STORES(W,'DECK4'))
                + sum(W, WT(W) * STORES(W,'DECK5'))
                + sum(W, WT(W) * STORES(W,'DECK9'))
                + sum(W, WT(W) * STORES(W,'DECK10'))
                + sum(W, WT(W) * STORES(W,'DECK14'))
                + sum(W, WT(W) * STORES(W,'DECK15'))
                + sum(W, WT(W) * STORES(W,'DECK19'))
```

```
                  + sum(W, WT(W) * STORES(W,'DECK20')) =G=
                     sum(W, WT(W) * STORES(W,'DECK1'))
                   + sum(W, WT(W) * STORES(W,'DECK2'))
                   + sum(W, WT(W) * STORES(W,'DECK3'))
                   + sum(W, WT(W) * STORES(W,'DECK6'))
                   + sum(W, WT(W) * STORES(W,'DECK7'))
                   + sum(W, WT(W) * STORES(W,'DECK8'))
                   + sum(W, WT(W) * STORES(W,'DECK11'))
                   + sum(W, WT(W) * STORES(W,'DECK12'))
                   + sum(W, WT(W) * STORES(W,'DECK13'))
                   + sum(W, WT(W) * STORES(W,'DECK16'))
                   + sum(W, WT(W) * STORES(W,'DECK17'))
                   + sum(W, WT(W) * STORES(W,'DECK18')) ;

  STAB4..            sum(W, WT(W) * STORES(W,'DECK4'))
                   + sum(W, WT(W) * STORES(W,'DECK9'))
                   + sum(W, WT(W) * STORES(W,'DECK14'))
                   + sum(W, WT(W) * STORES(W,'DECK19')) =G=
                   + sum(W, WT(W) * STORES(W,'DECK3'))
                   + sum(W, WT(W) * STORES(W,'DECK8'))
                   + sum(W, WT(W) * STORES(W,'DECK13'))
                   + sum(W, WT(W) * STORES(W,'DECK18')) ;

  STAB5..            sum(W, WT(W) * STORES(W,'DECK3'))
                   + sum(W, WT(W) * STORES(W,'DECK8'))
                   + sum(W, WT(W) * STORES(W,'DECK13'))
                   + sum(W, WT(W) * STORES(W,'DECK18')) =G=
                   + sum(W, WT(W) * STORES(W,'DECK2'))
                   + sum(W, WT(W) * STORES(W,'DECK7'))
                   + sum(W, WT(W) * STORES(W,'DECK12'))
                   + sum(W, WT(W) * STORES(W,'DECK17')) ;

  STAB6..            sum(W, WT(W) * STORES(W,'DECK2'))
                   + sum(W, WT(W) * STORES(W,'DECK7'))
                   + sum(W, WT(W) * STORES(W,'DECK12'))
                   + sum(W, WT(W) * STORES(W,'DECK17')) =G=
                   + sum(W, WT(W) * STORES(W,'DECK1'))
                   + sum(W, WT(W) * STORES(W,'DECK6'))
                   + sum(W, WT(W) * STORES(W,'DECK11'))
                   + sum(W, WT(W) * STORES(W,'DECK16')) ;

MODEL AOE3/ALL/;

SOLVE AOE3 USING MIP MAXIMIZING Z;

 PARAMETER NUMWEPS(W),NUMACC(W,AC);

 NUMWEPS(W)  = sum(D,STORES.L(W,D));
 NUMACC(W,AC)  = sum(D,ACC.L(W,AC,D));

 PARAMETERS VOLUSE(D),WTUSE(D);
```

```
VOLUSE(D) = sum(W, VOL(W) * STORES.L(W,D)) +
                 sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                 ACCVOL(AC)*ACC.L(W,AC,D)));
WTUSE(D) =  sum(W, WT(W) * STORES.L(W,D)) +
                 sum(AC, sum(W $ (REQACC(W,AC) GT 0),
                 ACCWT(AC)*ACC.L(W,AC,D)));

PARAMETER TONS;
TONS = (sum(D, WTUSE(D)) * 1000) / 2240 ;

DISPLAY WEPCMP;
DISPLAY STORES.L,ACC.L;
DISPLAY NUMWEPS,NUMACC;
DISPLAY VOLUSE,WTUSE;
DISPLAY TONS;
```

```
   S O L V E    S U M M A R Y
MODEL        AOE3       OBJECTIVE     Z
TYPE         MIP        DIRECTION     MAXIMIZE
SOLVER       XA         FROM LINE     474

**** SOLVER STATUS         1  NORMAL COMPLETION
**** MODEL STATUS          8  INTEGER SOLUTION
**** OBJECTIVE VALUE       128693.3473

                           ABSOLUTE            RELATIVE
ACTUAL DISTANCE             1924.15270          0.01473
TOLERANCES   (OPTCA)           0.00000 (OPTCR) 0.50000


----     495 PARAMETER WEPCMP

* WEPCOMP REMAINS THE SAME AS IN AOE-6 MODEL

----     496 VARIABLE  STORES.L    ordnance on each deck of type w
```

	DECK3	DECK4	DECK5	DECK6	DECK7	DECK8
SPA						20.00
SM2						20.00
CHF		16.10				
WAL		28.03		32.60		
HRM	121.46					
RCK		107.23	42.77			
MVK		28.35				
ASR		15.00				
1LB					109.02	
5LB					98.38	
PRO						148.18

```
  +  DECK9        DECK11      DECK12       DECK14      DECK15      DECK18
```

```
CHF   133.90
SNB                                                150.00
WAL                                                          89.37
HRM                                  78.54
MVK                       121.65
HLF                                  75.00
HAR                                                 15.00
2LB                                                                     155.02
1LB                                                            140.98
5LB   151.62

  +    DECK19    DECK20


SID    83.85
PHO    10.00
CWS    80.00
SSP              25.00
M60    10.00
M46              15.00
2LB              81.46
```

```
----     496 VARIABLE  ACC.L    accessories for each weapon and
                                deck stored on

                DECK1        DECK2        DECK5        DECK6        DECK7

WAL.WALWF                    15.42
ASR.ASRIA                                                           15.00
2LB.2LBF                                  68.08
1LB.1LBF                    250.00
5LB.5LBF        45.61
PRO.PROC                                               148.18

          +    DECK10       DECK12       DECK13       DECK16       DECK18

WAL.WALWF                                              134.58
HAR.HARW        10.92         4.08
HAR.HARF                     15.00
M46.M46IA                                                           15.00
2LB.2LBF       165.94                                                2.47
5LB.5LBF                                  204.39
```

```
----     497 PARAMETER NUMWEPS

SID   83.85,    SPA   20.00,   PHO   10.00, SM2   20.00, CHF 150.00
SNB 150.00,     WAL 150.00,    HRM 200.00, RCK 150.00, MVK 150.00
HLF   75.00,    HAR   15.00,   CWS   80.00, SSP   25.00, M60  10.00
M46   15.00,    ASR   15.00,   2LB 236.49, 1LB 250.00, 5LB 250.00
PRO 148.18
```

```
----     497 PARAMETER NUMACC

          WALWF      HARF       HARW       M46IA      ASRIA      2LBF

WAL      150.00
HAR                 15.00      15.00
M46                                        15.00
ASR                                                   15.00
2LB                                                              236.49

  +        1LBF        5LBF        PROC

1LB       250.00
5LB                   250.00
PRO                               148.18


----     498 PARAMETER VOLUSE

DECK1   2828.00, DECK2   11610.00, DECK3   11417.50, DECK4 12672.00,
DECK5   6600.00, DECK6   9290.70, DECK7    7186.21, DECK8   9330.96,
DECK9   9690.00, DECK10 9690.00, DECK11   6447.69, DECK12 12672.00,
DECK13 12672.00, DECK14  9300.00, DECK15 12672.00,
DECK16 9690.00, DECK18 8684.36, DECK19   9690.00, DECK20  5875.47


----     498 PARAMETER WTUSE

DECK1    49.90, DECK2   202.78,  DECK3   291.51,  DECK4   340.16
DECK5   127.56, DECK6   370.00,  DECK7   635.00,  DECK8   635.00
DECK9   635.00, DECK10 135.15,  DECK11 137.47,  DECK12 278.14
DECK13 223.60, DECK14 253.33,  DECK15 682.93,  DECK16 155.17
DECK18 635.00, DECK19 354.83,  DECK20 365.30

PARAMETER TONS                    =       2905.28
```

APPENDIX K
SCENARIO 1 GAMS LINEAR PROGRAM

This Appendix provides the reader the opportunity to review the GAMS Battle Group Commodity Level Program code for Scenario 1. At the end of this Appendix, an example of the input file for the variable USED(I,T) will be displayed.

```
$STITLE      Commodity usage for a battle group
$STITLE      LT Bill Schmitt

*____________________GAMS AND DOLLAR CONTROL OPTIONS____________
$OFFUPPER  OFFSYMLIST  OFFSYMXREF
OPTIONS
MIP = XA,     RMIP = XA
LIMCOL = 0,   LIMROW = 0,   SOLPRINT = OFF,   DECIMALS = 2
RESLIM = 5000,  ITERLIM = 25000,  OPTCR = 0.05,  SEED = 3141;

*_______________________________________________________________

*THESIS:  OPTIMIZE THE LOADOUT OF THE SUPPLY CLASS AOE

*_________ This section defines the sets _______________________
SET
I   commodities              / DFM
                               JP5
                               STORES
                               AMMO /

T   Days in the operation    / 1 * 80 /;

*_______________________________________________________________
*_______ This section defines and initializes the parameters_____

PARAMETERS

* set the minimum (scene 1) reserve levels in the BG.

* for this run 70%

MINLEVEL(I) minimum reserve levels for commodity I in the battle
group
                 / DFM          3964249.1
                   JP5          3648557.5
                   STORES       1160.9
                   AMMO         3511.2/

MAXLEVEL(I) max amount of commodity I in battle group
                 /DFM           7944676
```

```
                    JP5           7493687
                    STORES        1658.42
                    AMMO          5016     /;

*  this section will call in the table USED(I,T).  Due to the
*  the large size of the table, a separate input file has been
*  made for each scenario.

$INCLUDE F:SCEN1.TAB

*________________Variable section______________________________*


POSITIVE VARIABLES
INITAOE(I)  Find the initial(MAX) of each commodity

AOE6(I,T)   Amount of commodity I in battle group at end of day T

CONSOL(I,T) Amount of commodity I transferred to battle group by
           station ships on day t;

INITAOE.UP('DFM') = 7944676;
INITAOE.LO('DFM') = 5663213;
INITAOE.LO('JP5') = 5212225;
INITAOE.UP('JP5') = 7493687;

VARIABLE

OBJECT     minimize the number of consoles;

BINARY VARIABLE

DAY(T)     Yes or no decision to CONSOL on day T;

*___________________EQUATIONS___________________________________*

EQUATIONS
RESUPPLY         Objective function
NUMCONS          minimize the number of CONSOL's allowed
DAYONE(I,T)      state of AOE after day one
RESERVE(I,T)     commodity flow balanced equation
MIN(I,T)         when to replenish
MAX(I,T)         do not overfill
CONOPS(I,T)      how much of commodity I to CONSOL on day T
LSTORE           load stores
LAMMO            load ammo
FUELMIX          look at the split of JP-5 to DFM;


RESUPPLY..      OBJECT =E= sum(I, sum(t,CONSOL(I,T)));
```

```
NUMCONS..          sum(T, DAY(T)) =E= 7;
DAYONE(I,T)..      AOE6(I,'1') =E= INITAOE(I) - USED(I,'1') +
CONSOL(i,'1');
RESERVE(I,T) $ (ord(T) gt 1)..
                   AOE6(I,T) =E= AOE6(I,T-1) - USED(I,T)
                                              + CONSOL(I,T);
MIN(I,T)..         AOE6(I,T) =G= MINLEVEL(I);
MAX(I,T)..         AOE6(I,T) =L= INITAOE(I);
CONOPS(I,T)..      CONSOL(I,T) =L= MAXLEVEL(I) * DAY(T);
LSTORE..           INITAOE('STORES') =E= 1658.42;
LAMMO..            INITAOE('AMMO') =E= 5016;


FUELMIX..          INITAOE('DFM')+INITAOE('JP5') =E= 13156901 * .95;


MODEL SUPPLY/ALL/;
SOLVE SUPPLY USING MIP MAXIMIZING OBJECT;

PARAMETER
TOTUSE(I)
TOTCON(I);

TOTUSE(I) = sum(T,USED(I,T));
TOTCON(I) = sum(T,CONSOL.L(I,T));

PARAMETER
JPMIX,DFMIX;

JPMIX = (INITAOE.L('JP5') - (2400000 * .95)) / (7056900 * .95);
DFMIX = (INITAOE.L('DFM') - (3700000 * .95)) / (7056900 * .95);


DISPLAY
INITAOE.L,JPMIX,DFMIX,DAY.L,CONSOL.L,AOE6.L,TOTUSE,TOTCON;
```

The following is an example of the file SCEN1.TAB that is used to enter the Battle group daily commodity consumption into the GAMS model:

```
TABLE USED(I,T) Amount of commodity I expended on day T

*Transit
        1      2      3      4      5      6      7      8      9      10
DFM     327024 327024 327024 327024 327024 327024 327024 327024 327024 327024
JP5     106250 106250 106250 106250 106250 106250 106250 106250 106250 106250
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO     0     0      0      0      0      0      0      0      0      0

*Presence
+       11     12     13     14     15     16     17     18     19     20
DFM     188905 188905 188905 188905 188905 188905 188905 188905 188905 188905
JP5     106250 106250 106250 106250 106250 106250 106250 106250 106250 106250
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    10     10     10     10     10     10     10     10     10     10



+       21     22     23     24     25     26     27     28     29     30
DFM     188905 188905 188905 188905 188905 188905 188905 188905 188905 188905
JP5     106250 106250 106250 106250 106250 106250 106250 106250 106250 106250
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    10     10     10     10     10     10     10     10     10     10

+       31     32     33     34     35     36     37     38     39     40
DFM     188905 188905 188905 188905 188905 188905 188905 188905 188905 188905
JP5     106250 106250 106250 106250 106250 106250 106250 106250 106250 106250
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    10     10     10     10     10     10     10     10     10     10

*Combat
+       41     42     43     44     45     46     47     48     49     50
DFM     227945 227945 227945 227945 227945 227945 227945 227945 227945 227945
JP5     212500 212500 212500 212500 212500 212500 212500 212500 212500 212500
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    100    100    100    100    100    100    100    100    100    100

+       51     52     53     54     55     56     57     58     59     60
DFM     227945 227945 227945 227945 227945 227945 227945 227945 227945 227945
JP5     212500 212500 212500 212500 212500 212500 212500 212500 212500 212500
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    100    100    100    100    100    100    100    100    100    100

+       61     62     63     64     65     66     67     68     69     70
DFM     227945 227945 227945 227945 227945 227945 227945 227945 227945 227945
JP5     212500 212500 212500 212500 212500 212500 212500 212500 212500 212500
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    100    100    100    100    100    100    100    100    100    100

+       71     72     73     74     75     76     77     78     79     80
DFM     227945 227945 227945 227945 227945 227945 227945 227945 227945 227945
JP5     212500 212500 212500 212500 212500 212500 212500 212500 212500 212500
STORES  32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5   32.5
AMMO    100    100    100    100    100    100    100    100    100    100  ;
```

APPENDIX L. RESULTS OF CARGO FUEL MODEL PROGRAM

This Appendix provides the reader the opportunity to review the results of the Battle Group Commodity level program indepth. The results contained in this Appendix are from the example program shown in Appendix K. These results are for Scenario 1, with a 70% commodity reserve level:

```
MODEL STATISTICS

BLOCKS OF EQUATIONS      10       SINGLE EQUATIONS      1601
BLOCKS OF VARIABLES      5        SINGLE VARIABLES       725
NON ZERO ELEMENTS        3913     DISCRETE VARIABLES      80
GENERATION TIME     =      1.420 SECONDS
EXECUTION TIME      =      1.530 SECONDS

               S O L V E      S U M M A R Y

     MODEL   SUPPLY                     OBJECTIVE  OBJECT
     TYPE    MIP                        DIRECTION  MAXIMIZE
     SOLVER  XA                         FROM LINE  164

**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       8 INTEGER SOLUTION
**** OBJECTIVE VALUE    25965737.5000

 RESOURCE USAGE, LIMIT          96.000      5000.000
 ITERATION COUNT, LIMIT        934         35000

No better solution than : 30812090.00
                        Absolute                     Relative
Actual distance       4846352.500                    0.15729
Tolerances     (OPTCA)     0.00000    (OPTCR)        0.50000

----     180 VARIABLE  INITAOE.L      Find the initial(MAX) of each
                                        commodity

DFM    6512998.45,     JP5     5986057.50,     STORES     1658.42
AMMO      5016.00


----     180 PARAMETER JPMIX                   =            0.55
             PARAMETER DFMIX                   =            0.45
```

---- 180 VARIABLE DAY.L Yes or no decision to CONSOL on day T

8 1.00, 10 1.00, 24 1.00, 35 1.00, 48 1.00, 57 1.00, 69 1.00

---- 180 VARIABLE CONSOL.L Amount of commodity I transferred to battle group

	8	10	24	35	48	57
DFM	394466.65	2875773.35	2644670.00	2077955.00	2042895.65	2776694.35
JP5	106250.00		1168750.00	2125000.00	1912500.00	2550000.00
STORES		325.00	282.48	422.50	292.50	390.00
AMMO					395.20	1200.00

+	69
DFM	2735340.00
JP5	2550000.00
STORES	530.02
AMMO	1604.80

---- 180 VARIABLE AOE6.L Amount of commodity I in battle group at end of day T

	1	2	3	4	5	6
DFM	6185974.45	5858950.45	5531926.45	5204902.45	4877878.45	4550854.45
JP5	5879807.50	5773557.50	5667307.50	5561057.50	5454807.50	5348557.50
STORES	1625.92	1593.42	1560.92	1528.42	1495.92	1463.42
AMMO	5016.00	5016.00	5016.00	5016.00	5016.00	5016.00

+	7	8	9	10	11	12
DFM	4223830.45	4291273.10	3964249.10	6512998.45	6324093.45	6135188.45
JP5	5242307.50	5242307.50	5136057.50	5029807.50	4923557.50	4817307.50
STORES	1430.92	1398.42	1365.92	1658.42	1625.92	1593.42
AMMO	5016.00	5016.00	5016.00	5016.00	5006.00	4996.00

+	13	14	15	16	17	18
DFM	5946283.45	5757378.45	5568473.45	5379568.45	5190663.45	5001758.45
JP5	4711057.50	4604807.50	4498557.50	4392307.50	4286057.50	4179807.50
STORES	1560.92	1528.42	1495.92	1463.42	1430.92	1398.42
AMMO	4986.00	4976.00	4966.00	4956.00	4946.00	4936.00

+	19	20	21	22	23	24
DFM	4812853.45	4623948.45	4435043.45	4246138.45	4057233.45	6512998.45
JP5	4073557.50	3967307.50	3861057.50	3754807.50	3648557.50	4711057.50
STORES	1365.92	1333.42	1300.92	1268.42	1235.92	1485.90
AMMO	4926.00	4916.00	4906.00	4896.00	4886.00	4876.00

+	25	26	27	28	29	30
DFM	6324093.45	6135188.45	5946283.45	5757378.45	5568473.45	5379568.45
JP5	4604807.50	4498557.50	4392307.50	4286057.50	4179807.50	4073557.50
STORES	1453.40	1420.90	1388.40	1355.90	1323.40	1290.90
AMMO	4866.00	4856.00	4846.00	4836.00	4826.00	4816.00

+	31	32	33	34	35	36
DFM	5190663.45	5001758.45	4812853.45	4623948.45	6512998.45	6324093.45
JP5	3967307.50	3861057.50	3754807.50	3648557.50	5667307.50	5561057.50
STORES	1258.40	1225.90	1193.40	1160.90	1550.90	1518.40
AMMO	4806.00	4796.00	4786.00	4776.00	4766.00	4756.00

+	37	38	39	40	41	42
DFM	6135188.45	5946283.45	5757378.45	5568473.45	5340528.45	5112583.45
JP5	5454807.50	5348557.50	5242307.50	5136057.50	4923557.50	4711057.50
STORES	1485.90	1453.40	1420.90	1388.40	1355.90	1323.40
AMMO	4746.00	4736.00	4726.00	4716.00	4616.00	4516.00

+	43	44	45	46	47	48
DFM	4884638.45	4656693.45	4428748.45	4200803.45	3972858.45	5787809.10
JP5	4498557.50	4286057.50	4073557.50	3861057.50	3648557.50	5348557.50
STORES	1290.90	1258.40	1225.90	1193.40	1160.90	1420.90
AMMO	4416.00	4316.00	4216.00	4116.00	4016.00	4311.20

+	49	50	51	52	53	54
DFM	5559864.10	5331919.10	5103974.10	4876029.10	4648084.10	4420139.10
JP5	5136057.50	4923557.50	4711057.50	4498557.50	4286057.50	4073557.50
STORES	1388.40	1355.90	1323.40	1290.90	1258.40	1225.90
AMMO	4211.20	4111.20	4011.20	3911.20	3811.20	3711.20

+	55	56	57	58	59	60
DFM	4192194.10	3964249.10	6512998.45	6285053.45	6057108.45	5829163.45
JP5	3861057.50	3648557.50	5986057.50	5773557.50	5561057.50	5348557.50
STORES	1193.40	1160.90	1518.40	1485.90	1453.40	1420.90
AMMO	3611.20	3511.20	4611.20	4511.20	4411.20	4311.20

+	61	62	63	64	65	66
DFM	5601218.45	5373273.45	5145328.45	4917383.45	4689438.45	4461493.45
JP5	5136057.50	4923557.50	4711057.50	4498557.50	4286057.50	4073557.50
STORES	1388.40	1355.90	1323.40	1290.90	1258.40	1225.90
AMMO	4211.20	4111.20	4011.20	3911.20	3811.20	3711.20

+	67	68	69	70	71	72
DFM	4233548.45	4005603.45	6512998.45	6285053.45	6057108.45	5829163.45
JP5	3861057.50	3648557.50	5986057.50	5773557.50	5561057.50	5348557.50
STORES	1193.40	1160.90	1658.42	1625.92	1593.42	1560.92
AMMO	3611.20	3511.20	5016.00	4916.00	4816.00	4716.00

+	73	74	75	76	77	78

DFM	5601218.45	5373273.45	5145328.45	4917383.45	4689438.45	4461493.45
JP5	5136057.50	4923557.50	4711057.50	4498557.50	4286057.50	4073557.50
STORES	1528.42	1495.92	1463.42	1430.92	1398.42	1365.92
AMMO	4616.00	4516.00	4416.00	4316.00	4216.00	4116.00

+	79	80
DFM	4233548.45	4005603.45
JP5	3861057.50	3648557.50
STORES	1333.42	1300.92
AMMO	4016.00	3916.00

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DFM 18055190.00, JP5 12750000.00, STORES 2600.00
AMMO 4300.00

---- 180 PARAMETER TOTCON

DFM 15547795.00, JP5 10412500.00, STORES 2242.50
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